7. TAG 3 (PACS) TESTING

This section describes the test plan, methodology, and results for the technology field trial conducted by TAG 3. The technology tested was the PACS PCS standard. The base station (called radio port or RP in this technology) and base station controller (called radio port control unit or RPCU in this technology) equipment was provided by NEC. The mobile units (called subscriber units in this technology) were supplied by Motorola and Panasonic. The TAG 3 field tests examined area coverage, handoff, and voice quality; and the effects of co-channel and adjacent channel interference on system performance.

The information presented in this section is taken from [6]. The reader is referred to [6] for a more complete and detailed presentation of the TAG 3 technology field testing at the BITB.

7.1 TAG 3 Test System Configuration

The block diagram of the test system configuration is shown in Figure 7.1. As discussed in Section 2.0, the TAG 3 PACS technology was tested only in a low-tier configuration in seven different microcells. The previous technologies tested in the JTC PCS technology field trials were tested in a high-tier configuration only.

The test system consisted of a base station (RP) at each of four microcell sites in downtown Boulder, Colorado and three microcell sites in south Boulder. The base stations at each microcell site used receive antenna diversity. The base station controllers (RPCU's) were located in the WCO. The base stations were connected to the base station controllers by high-speed digital subscriber loop circuits providing T1 connectivity between the base station controllers and the base stations. Fiber optic transport was used between the high-speed digital subscriber loop terminals at the TMCO and the base station controller located at the WCO.

7.2 Calibration

A calibration of the base station RSS was performed by injecting a digitally modulated signal of known level into the receiver and comparing this level to the RSS value reported by the receiver.

The input signal into the base station receiver was provided by a digital modulation signal generator. Losses in the cabling between the signal generator and the input of the base station receiver were measured and a correction, or offset, was added to the signal generator output level reading. The level of the input signal was varied over the dynamic range of the receiver to generate a table of actual input RSS values and their corresponding reported RSS values. Note that although the base station provides diversity reception, it does not allow the intentional selection of a diversity branch. Since the base station normally operates on diversity branch 1, all calibrations were conducted on this branch; calibrations were not conducted on diversity branch 2. The maximum difference between the actual input RSS values and their corresponding reported RSS values was 3 dB over the operating range of -60 to -108 dBm for all 7 base stations tested.

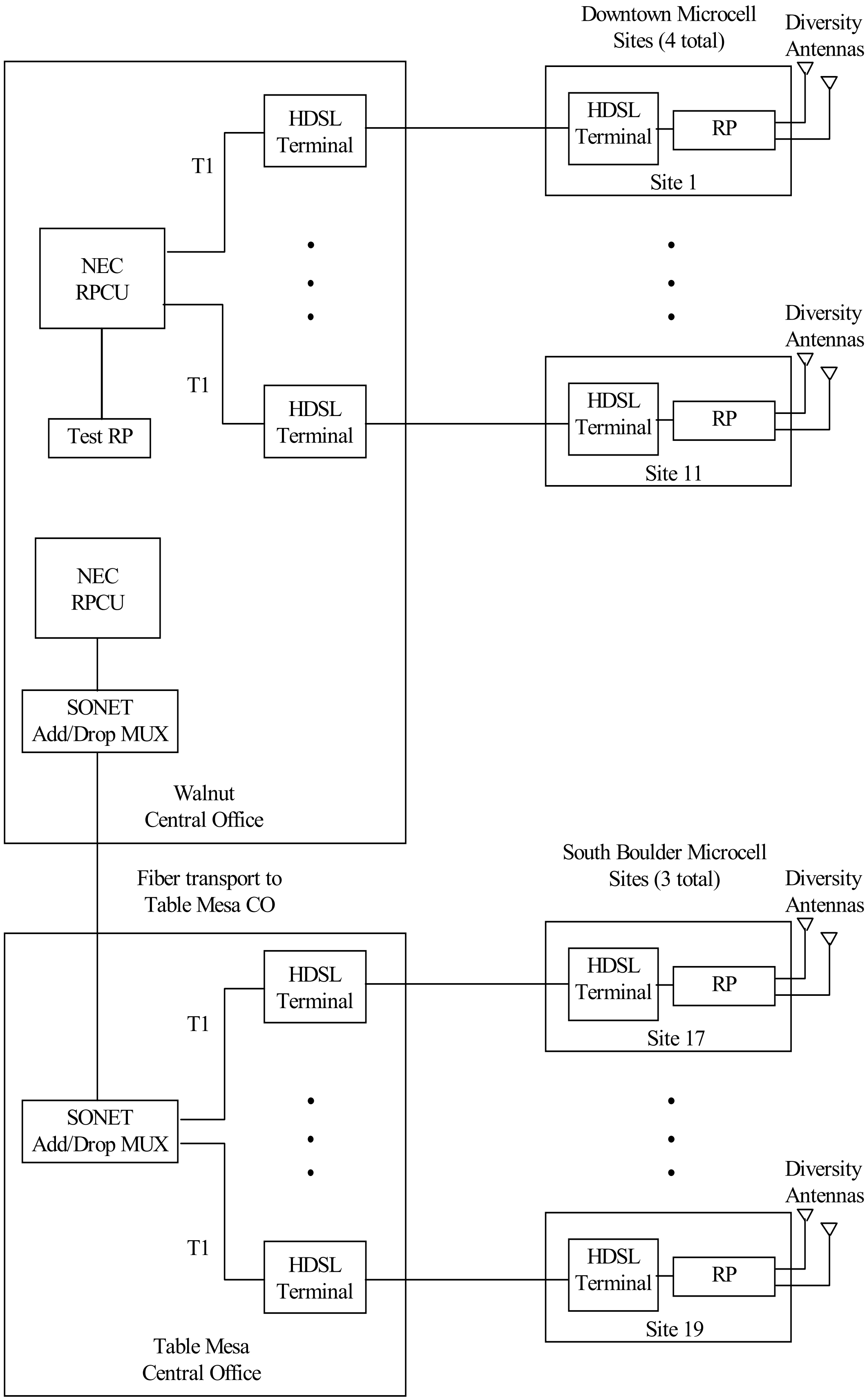


Figure 7.1. Block diagram of the TAG 3 test system configuration.

The mobile units (provided by Motorola and Panasonic) were checked for accuracy of the RSS reports. This was done by injecting a digitally modulated signal of known strength into the receiver of the mobile unit. The level of the input signal was then compared to the RSS value reported by the mobile unit. All of the mobile units had reported values of RSS within 4 dB of the actual input signal level for input signals from -45 to -100 dBm. Note that during the calibration procedure for the mobile units, receive diversity was enabled. With the receive diversity enabled, the mobile units report RSS from the strongest diversity branch.

An examination of the base station and mobile unit transmitter characteristics, including transmit power, frequency accuracy, modulation accuracy, and occupied bandwidth, was also performed; however, the results of this examination are not presented here.

7.3 Area Coverage Testing

Area coverage testing was performed in the four microcells located in downtown Boulder. These microcells, as described in Section 2.0 are:

Site 1 - Intersection of Pearl Street and Broadway
Site 3 - Intersection of Pearl Street and 15th Street
Site 9 - On 13th Street halfway between Pine Street and Mapleton Avenue
Site 11 - On 16th Street halfway between Pine Street and Mapleton Avenue

The base station power for each microcell site was set so that the output power was approximately 3.2 W equivalent isotropically radiated power (EIRP). Each base station used omnidirectional antennas. Measurements to show area coverage were taken with the mobile unit placed on a cart and with the antenna mounted on a wooden pole attached to the side of the cart. A Motorola mobile unit was used for all of the area coverage testing. A GPS receiver was mounted on the side of the cart next to the antenna mounting structure. The measurements were taken by pushing the cart at a pedestrian speed along routes (radials) away from the microcell site. When time permitted, measurements along additional routes in between the radials were taken.

Only one microcell site was activated at a time during area coverage testing; all other microcell sites were powered down. Calls were originated prior to the start of the route, approximately one half block away from the microcell site and data collection was initiated. The data were collected both at the mobile unit and at the base station as the measurement cart was pushed along the route. At the end of the route, the data collection was stopped and the data were saved to disk. If the call was dropped before the end of the route was reached, data collection was terminated and the data were saved to disk. The data collected at the mobile unit included GPS location and time, downlink RSS, downlink word error rate[13] (WER), and other system parameters. The data collected at the base station included GPS time, uplink RSS, uplink WER[13], and other system parameters. All data were averaged over 1 s.

[13] Actually, the number of errored frames per second (WERI) was recorded. The WER was computed from the following equation: WER = (WERI/400) • 100% since there are 400 frames per second.

7.3.1 Low-Tier Microcell Site 1 Area Coverage Data

Downlink RSS as a function of distance is shown in Figure 7.2. The data included in this figure are the overall data for this cell, excluding RSS values less than -101 dBm. RSS values less than -101 dBm were excluded because -101 dBm is the threshold level for normal system operation of the mobile unit receiver. The large variation in RSS seen in Figure 7.2 is mostly due to different propagation environments along Broadway and Pearl Street (foliage was heavier along Pearl Street) and shadowing. Note that signals up to approximately -88 dBm existed out to approximately 0.65 mi. Those signals were recorded along Broadway in areas having LOS propagation between the mobile unit and the base station.

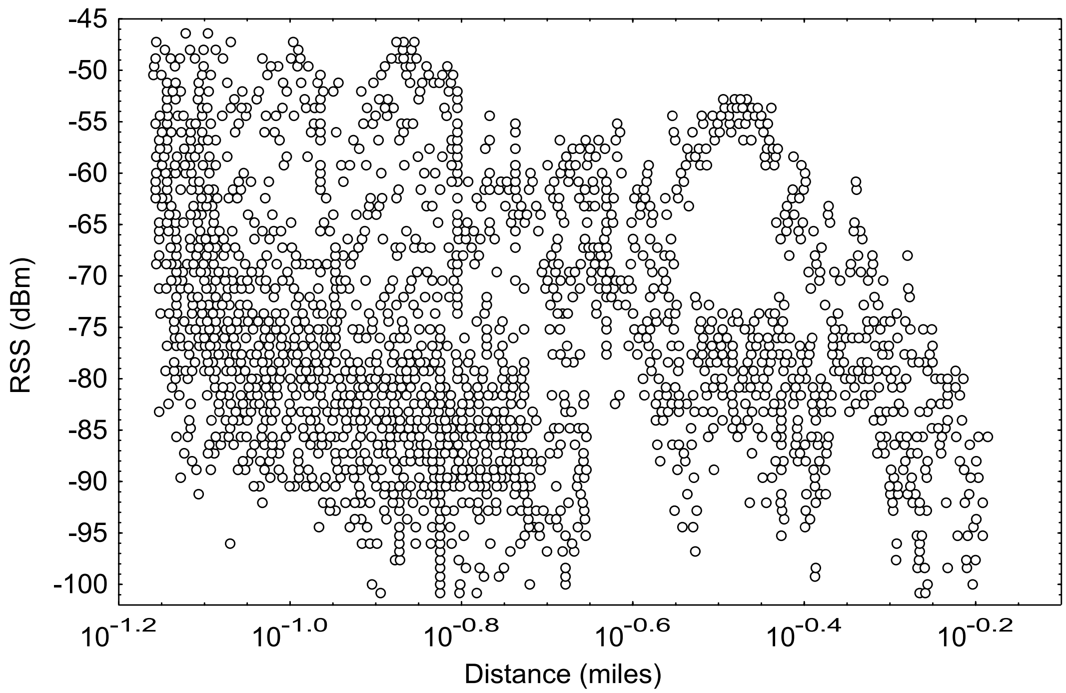


Figure 7.2. Downlink received signal strength (RSS) vs. distance (TAG 3, microcell site 1).

A rough estimate of the coverage area was determined by assuming that a downlink RSS of -90 dBm or greater is desired. The measured RSS data along all of the routes traversed within the microcell were used to determine the coverage area. Due to shadowing, the RSS varied significantly along the Site 1 routes, crossing the -90 dBm level several times before finally staying below -90 dBm. The point along each route where the RSS first dropped below -90 dBm was used to define the coverage boundaries. Under these conditions, the coverage boundaries were approximately 0.41 mi to the north-northwest, 0.35 mi to the west-southwest, and 0.57 mi to the south-southeast.

Figure 7.3 shows the histogram of downlink RSS values. Again, RSS values less than -101 dBm were excluded. The mean RSS was -75.9 dBm and the standard deviation was 12.95 dB. Figure 7.4 shows the histogram of downlink WER values. From this histogram it is seen that most of the data points had a WER less than or equal to 1%. One influencing factor on the WER is that the WER increases rapidly as the RSS approaches the -101-dBm threshold level (such as at the edge of the coverage area).

The histogram of uplink RSS values is shown in Figure 7.5. In this histogram, RSS values less than -118 dBm were excluded. The mean RSS was -91.24 dBm and the standard deviation was 11.28 dB for this case. Figure 7.6 shows the uplink WER histogram. Here, most of the data points had a WER less than or equal to 3%. A relatively large number of data points had a WER greater than 10%.

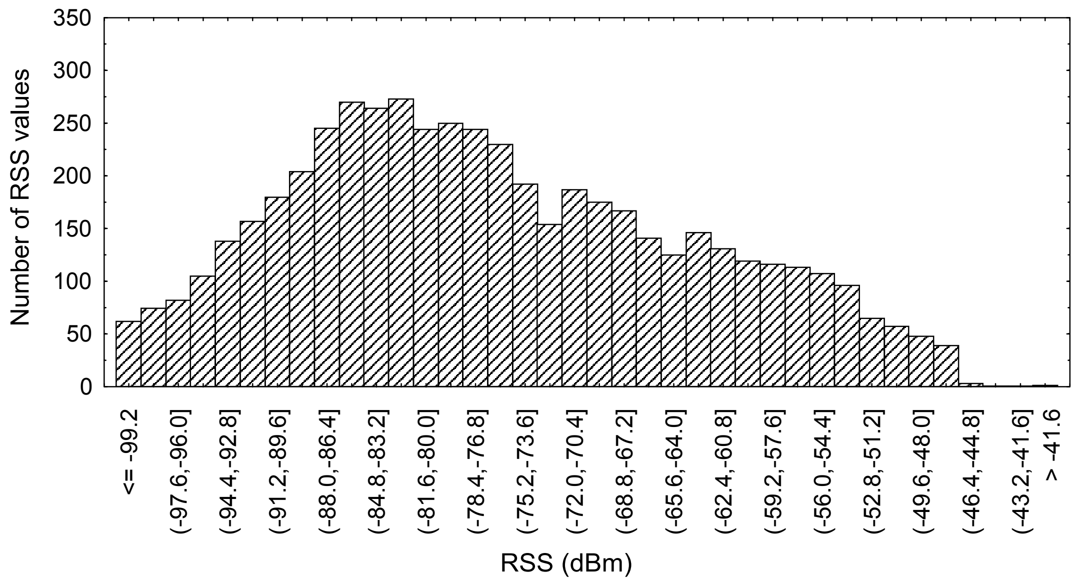


Figure 7.3. Histogram of downlink received signal strength (RSS; TAG 3, microcell site 1).

7.3.2 Low-Tier Microcell Site 3 Area Coverage Data

Downlink RSS as a function of distance is shown in Figure 7.7. The data included in this figure are the overall data for this cell, excluding RSS values less than -101 dBm. The large variation in RSS seen in Figure 7.7 occurs mostly because the base station was mounted on a light pole in the middle of the street which made shadowing more pronounced. Note that signals up to approximately -65 dBm existed out to approximately 1.35 mi. Those signals were recorded along 15th Street where a clear LOS propagation path existed between the mobile unit and the base station.

The estimate of the coverage area for Site 3 was determined in the same way as that for Site 1. The coverage boundaries were approximately 0.14 mi to the north-northwest, 0.26 mi to the west-southwest, and 0.36 mi to the south-southeast.

Figure 7.8 shows the histogram of downlink RSS values. Again, RSS values less than -101 dBm were excluded. The mean RSS was -74 dBm and the standard deviation was 15.81 dB. Figure 7.9 shows the histogram of downlink WER values. From this histogram it

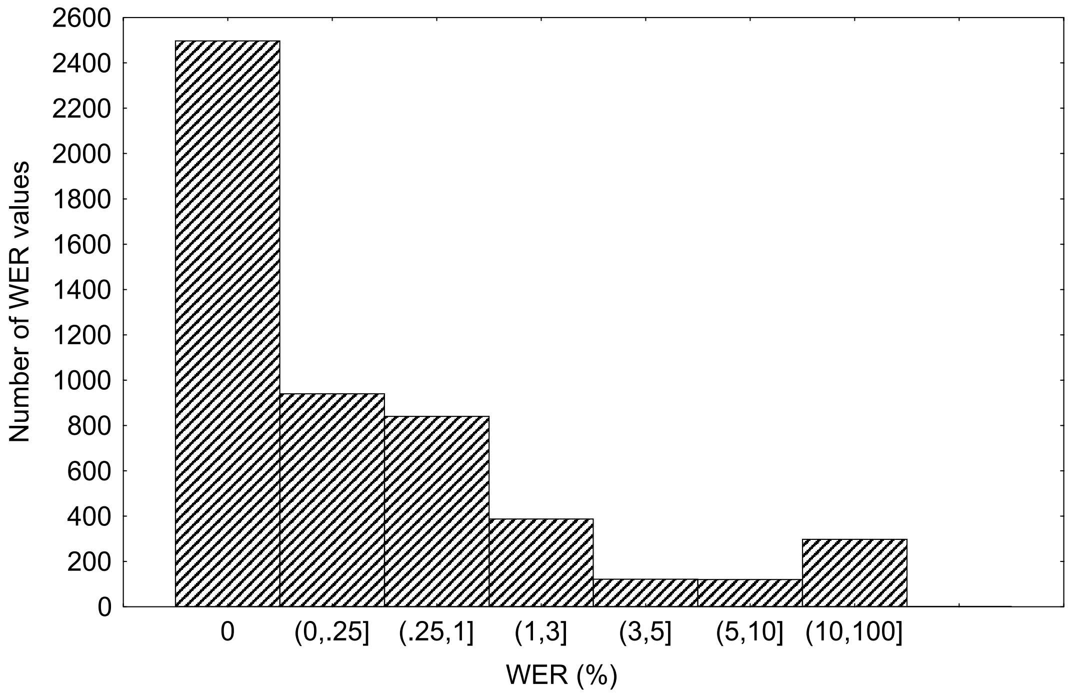


Figure 7.4. Histogram of downlink word error rate (WER; TAG 3, microcell site 1).

is seen that most of the data points had a WER less than or equal to 1%. The uplink RSS histogram is given in Figure 7.10. As in the uplink RSS histogram for Site 1, RSS values less than -118 dBm were excluded. The histogram shows a different distribution than for the downlink case in this microcell; RSS values around -70 dBm occur much more frequently than any other RSS values. The mean uplink RSS was -86 dBm and the standard deviation was 11.31 dB. Figure 7.11 shows the uplink WER histogram. Here, most of the data points had a WER less than or equal to 3%. A relatively large number of data points had a WER greater than 10%.

7.3.3 Low-Tier Microcell Site 9 Area Coverage Data

Downlink RSS as a function of distance is shown in Figure 7.12. The data included in this figure are the overall data for this cell, excluding RSS values less than -101 dBm. The large variation in RSS seen in Figure 7.12 occurs mostly because of shadowing in the environment and because the base station was mounted on a light pole in the middle of the street which made shadowing more pronounced. Note that signals up to approximately -83 dBm existed out to approximately 0.45 mi. Those signals were recorded in areas where a clear LOS propagation path existed between the mobile unit and the base station.

The estimate of the coverage area for Site 9 was determined in the same way as that for Site 1. The coverage boundaries were approximately 0.24 mi to the north-northwest, 0.42 mi to the west-southwest, and 0.24 mi to the west-northwest.

Figure 7.13 shows the histogram of downlink RSS values. Again, RSS values less than -101 dBm were excluded. The mean downlink RSS was -73.4 dBm and the standard deviation

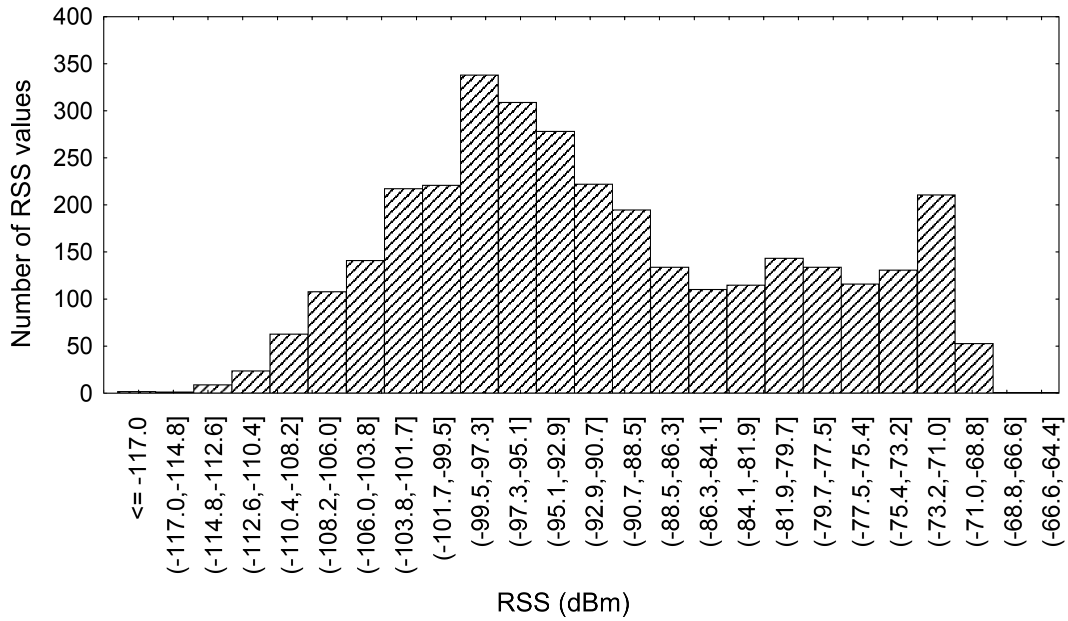


Figure 7.5. Histogram of uplink received signal strength (RSS; TAG 3, microcell site 1).

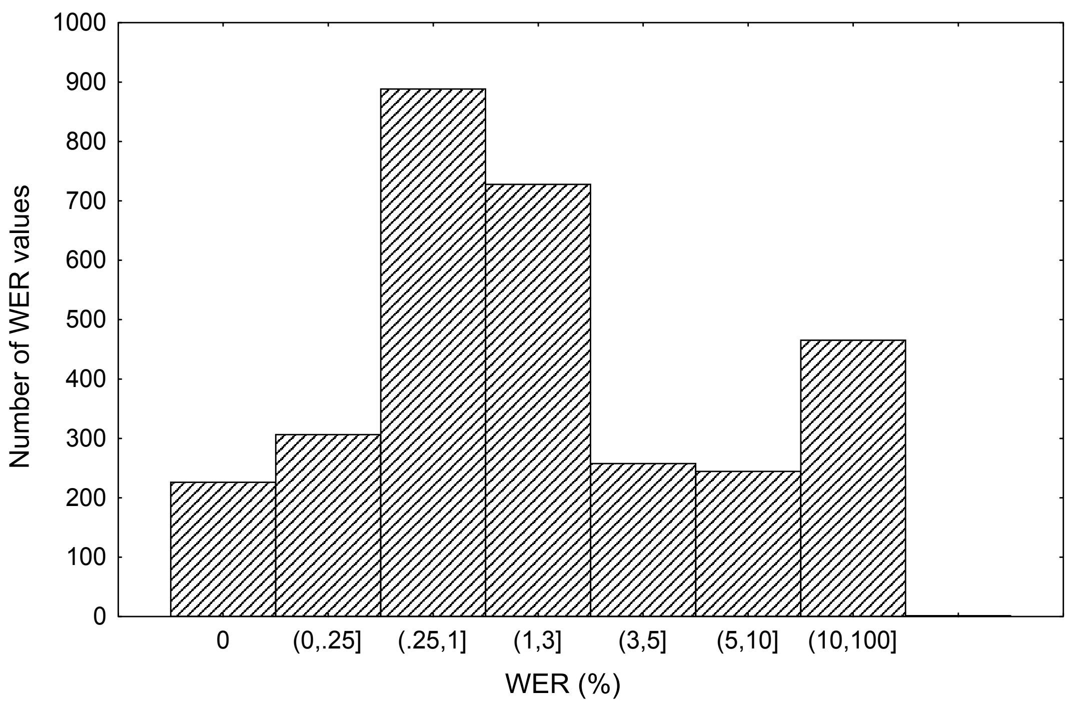


Figure 7.6. Histogram of uplink word error rate (WER; TAG 3, microcell site 1).

was 14.85 dB. Figure 7.14 shows the histogram of downlink WER values. From this histogram it is seen that most of the data points had a WER less than or equal to 0.25%. The uplink RSS histogram is given in Figure 7.15. As in the uplink RSS histogram for Site 1, RSS values less than -118 dBm were excluded. The histogram shows a different distribution than for the downlink case in this microcell; RSS values around -70 dBm occur much more

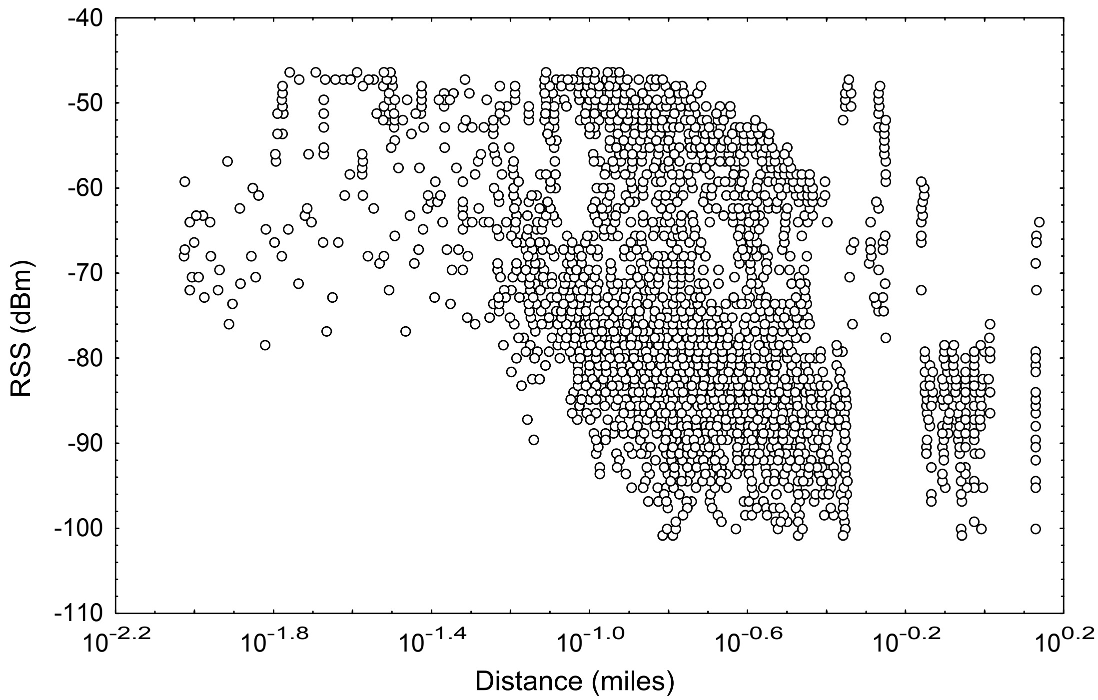


Figure 7.7. Downlink received signal strength (RSS) vs. distance (TAG 3, microcell site 3).

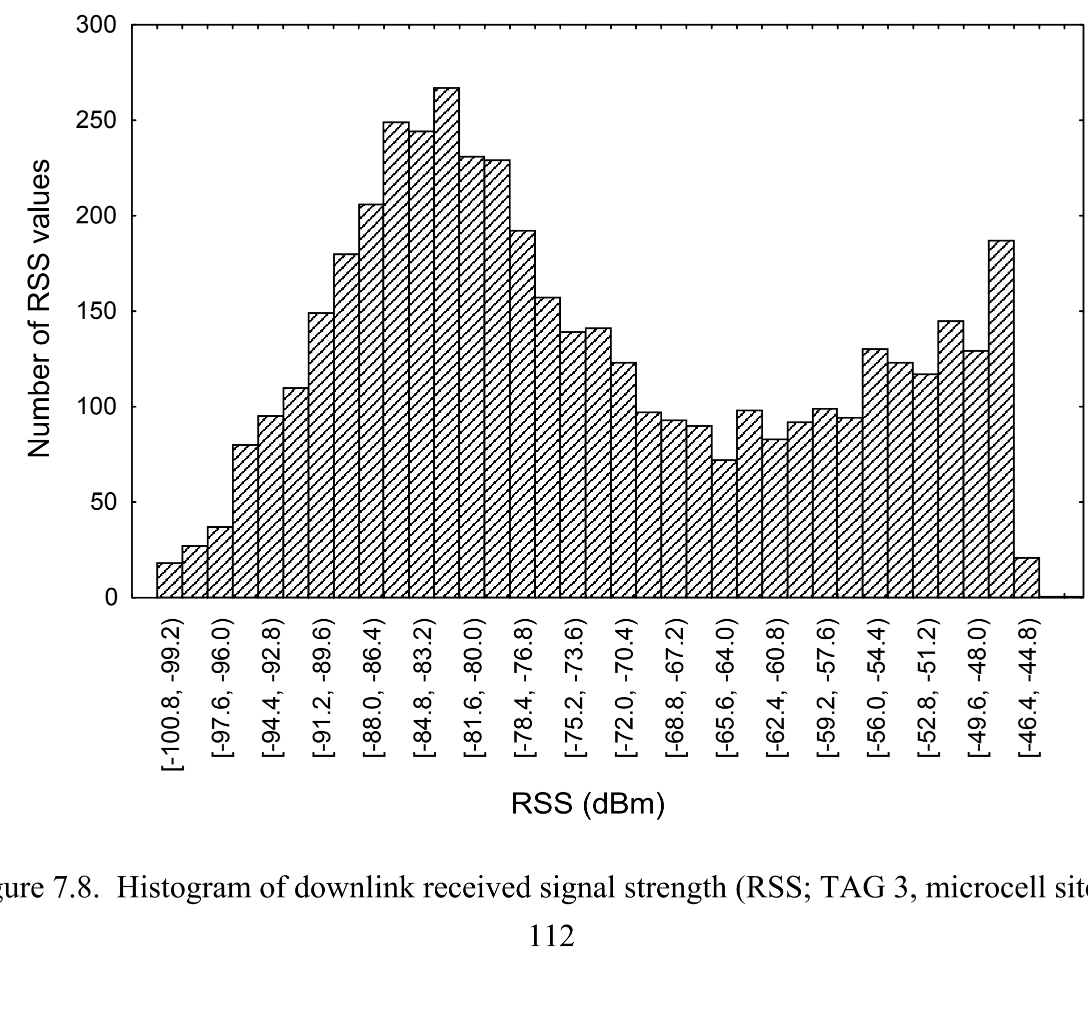


Figure 7.8. Histogram of downlink received signal strength (RSS; TAG 3, microcell site 3).

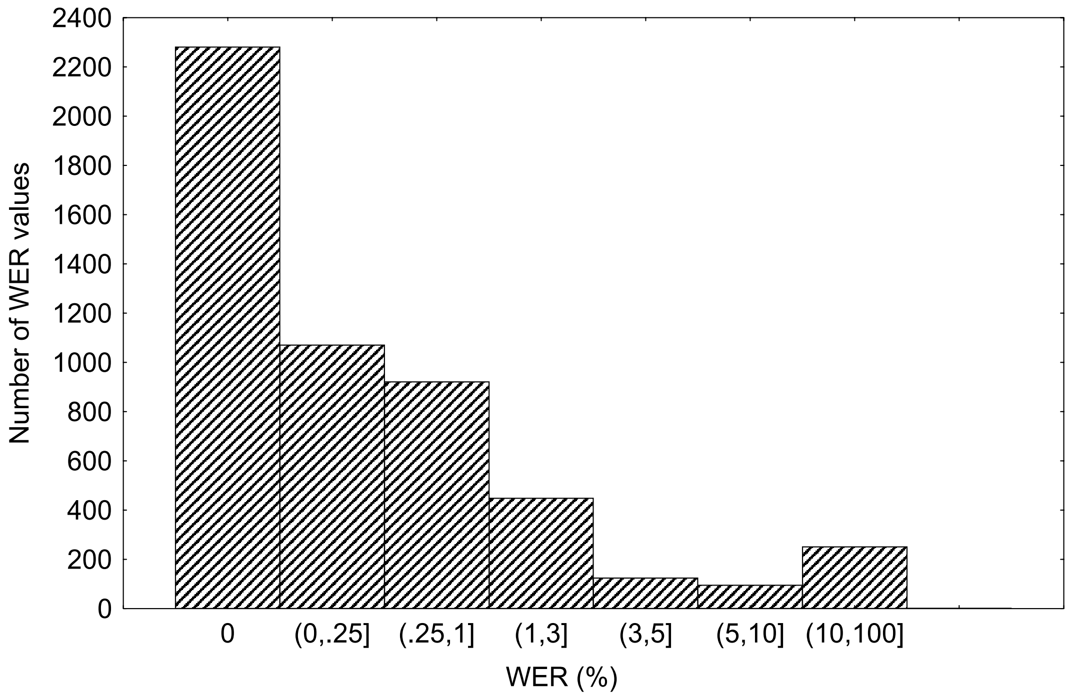


Figure 7.9. Histogram of downlink word error rate (WER; TAG 3, microcell site 3).

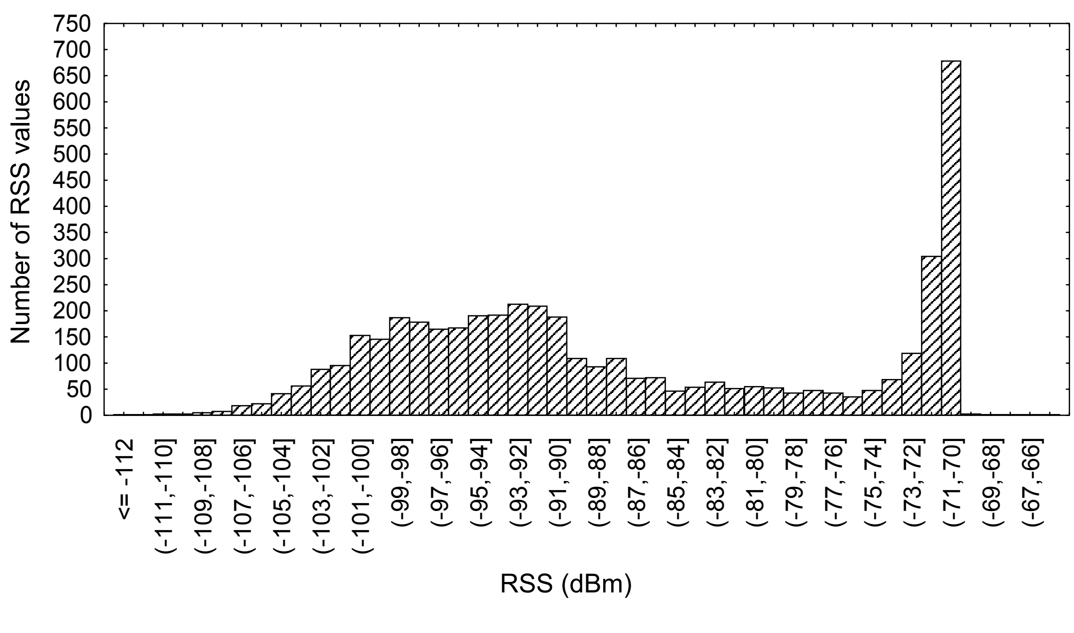


Figure 7.10. Histogram of uplink received signal strength (RSS; TAG 3, microcell site 3).

frequently than any other RSS values. The mean uplink RSS was -91.24 dBm and the standard deviation was 11.28 dB. Figure 7.16 shows the uplink WER histogram. Here most of the data points had a WER less than or equal to 3%. A relatively large number of data points had a WER greater than 10%.

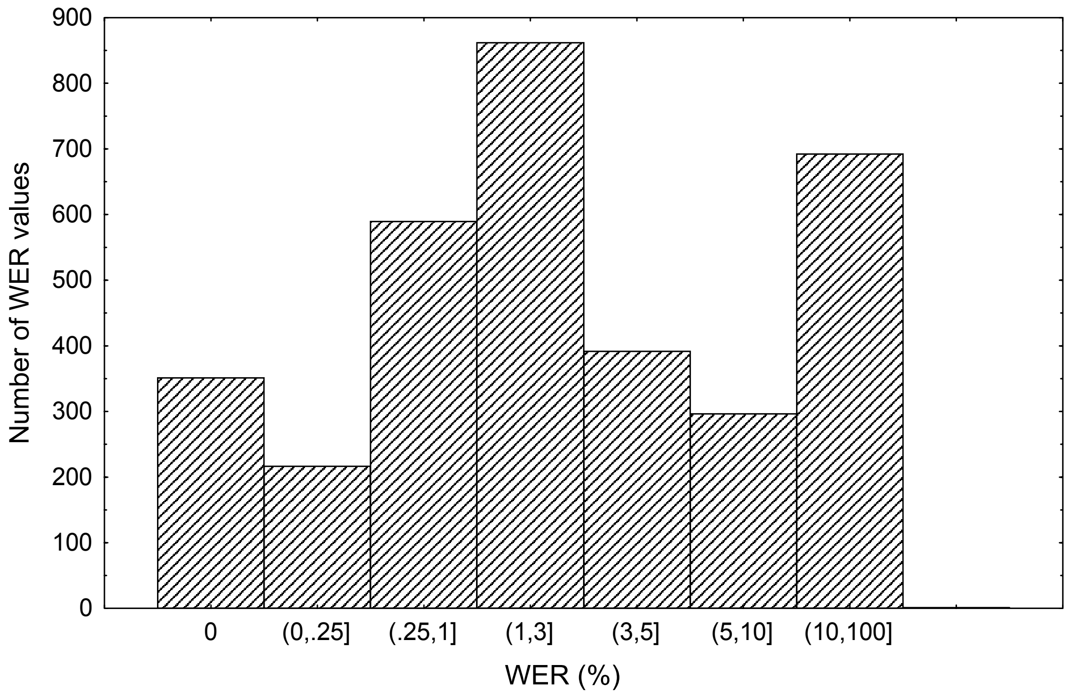


Figure 7.11. Histogram of uplink word error rate (WER; TAG 3, microcell site 3).

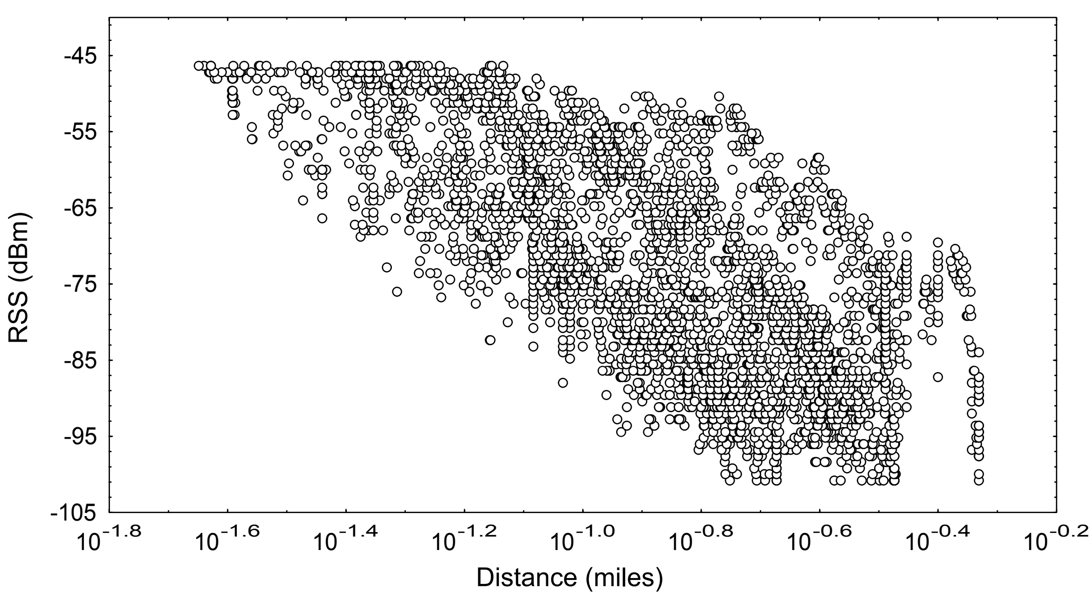


Figure 7.12. Downlink received signal strength (RSS) vs. distance (TAG 3, microcell site 9).

7.3.4 Low-Tier Microcell Site 11 Area Coverage Data

Downlink RSS as a function of distance is shown in Figure 7.17. The data included in this figure are the overall data for this cell, excluding RSS values less than -101 dBm. The large variation in

RSS seen in Figure 7.17 occurs mostly because of shadowing in the environment. Note that signals up to approximately -80 dBm existed out to approximately 0.50 mi. Those signals were recorded in areas where a clear LOS propagation path existed between the mobile unit and the base station.

The estimate of the coverage area for Site 11 was determined in the same way as that for Site 1. The coverage boundaries were approximately 0.35 mi to the west-southwest, 0.28 mi to the east-northeast, and 0.48 mi to the south-southeast. Since there is a hill immediately north of Site 11 that obstructed coverage in that direction, very little data were collected there.

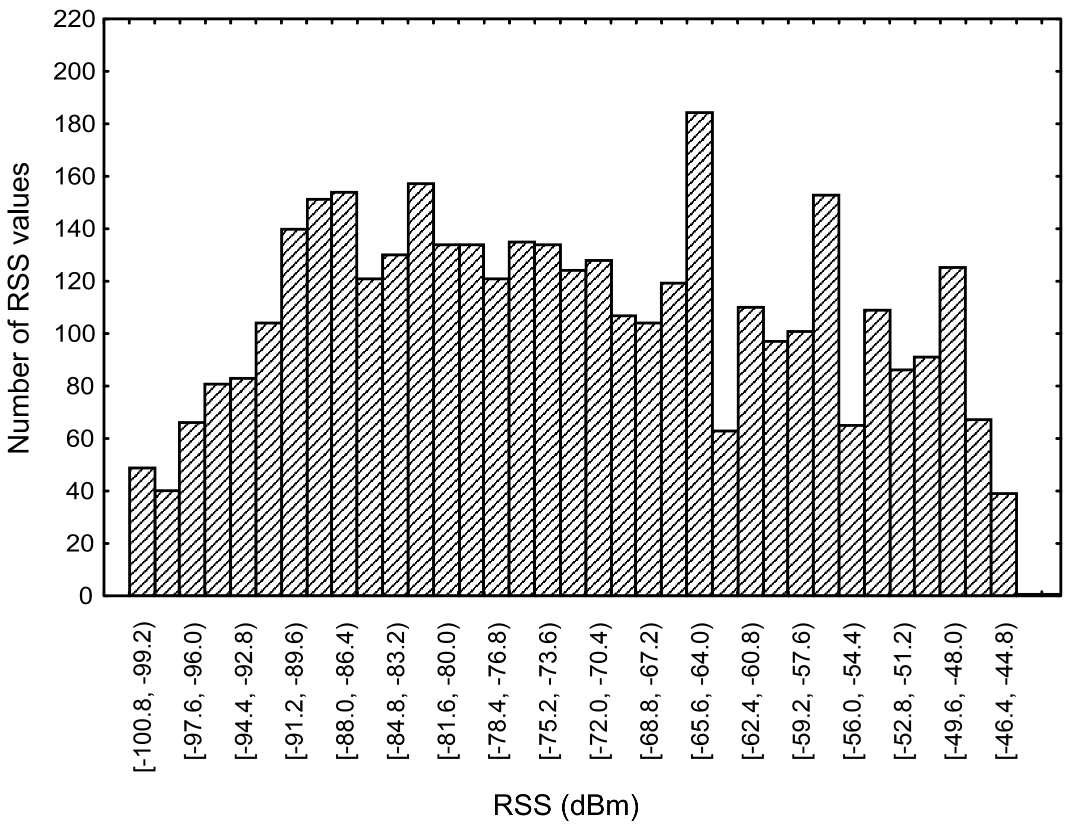


Figure 7.13. Histogram of downlink received signal strength (RSS; TAG 3, microcell site 9).

Figure 7.18 shows the histogram of downlink RSS values. Again, RSS values less than -101 dBm were excluded. The mean downlink RSS was -74.14 dBm and the standard deviation was 13.28 dB. Figure 7.19 shows the histogram of downlink WER values. From this histogram it is seen that most of the data points had a WER less than or equal to 0.1%. The uplink RSS histogram is given in Figure 7.20. As in the uplink RSS histogram for Site 1, RSS values less than -118 dBm were excluded. The histogram shows a different distribution than for the downlink case in this microcell; RSS values around -71 dBm occur much more frequently than any other RSS values. The mean uplink RSS was -88.79 dBm and the standard deviation was 11.95 dB. Figure 7.21 shows the uplink WER histogram. This histogram shows that higher uplink WER’s were more prevalent in this microcell. A large number of data points had a WER greater than 5%.

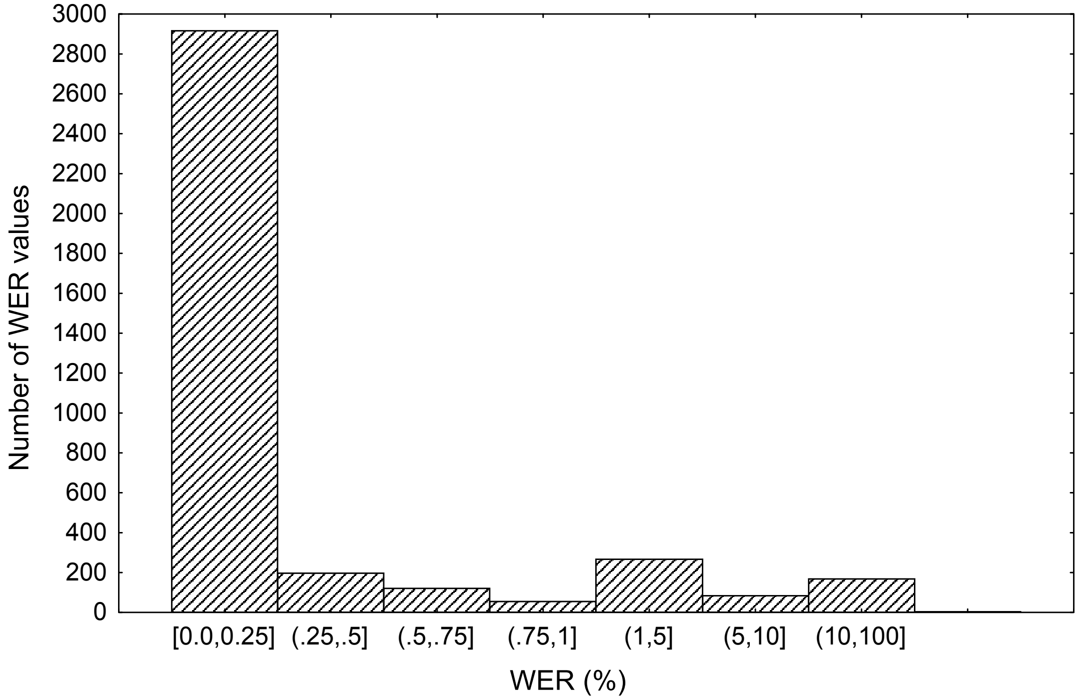


Figure 7.14. Histogram of downlink word error rate (WER; TAG 3, microcell site 9).

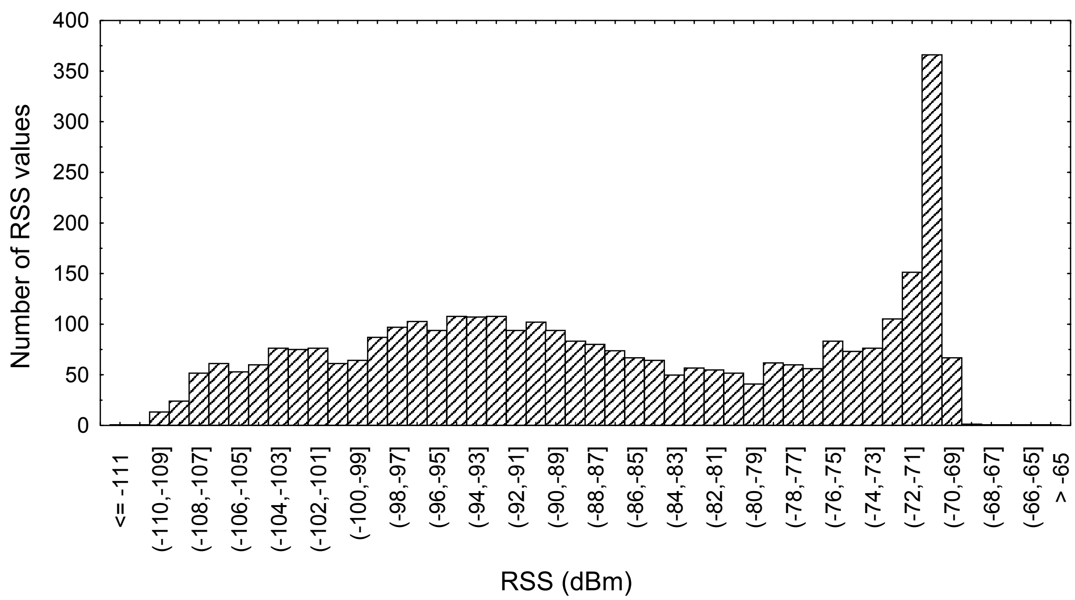


Figure 7.15. Histogram of uplink received signal strength (RSS; TAG 3, microcell site 9).

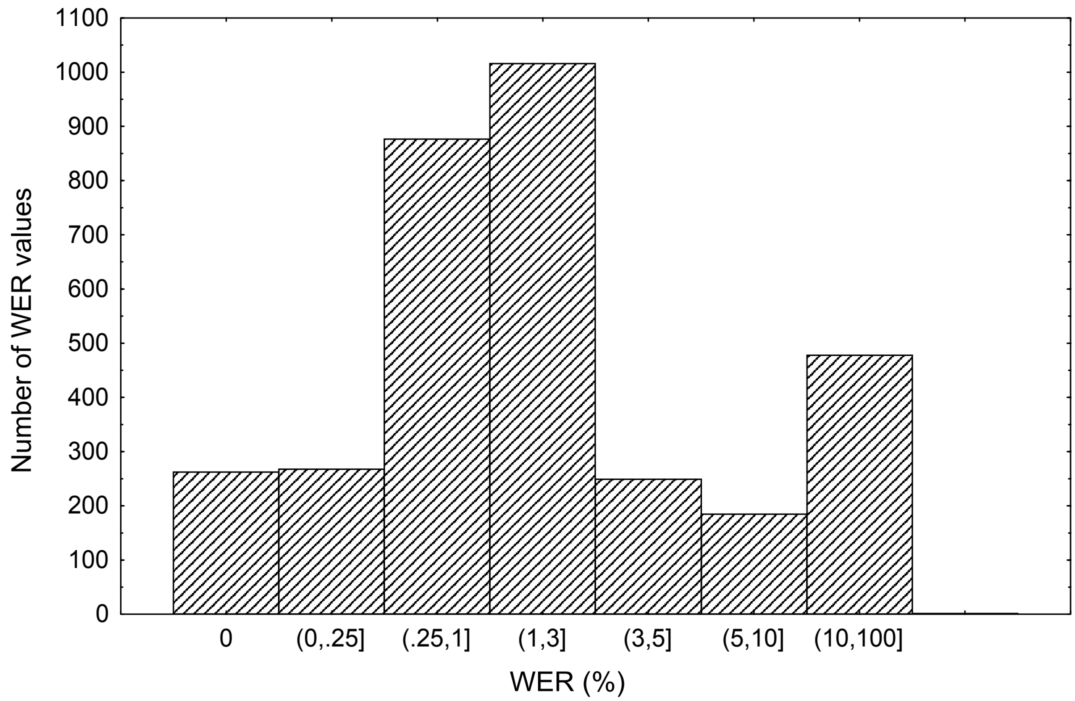


Figure 7.16. Histogram of uplink word error rate (WER; TAG 3, microcell site 9).

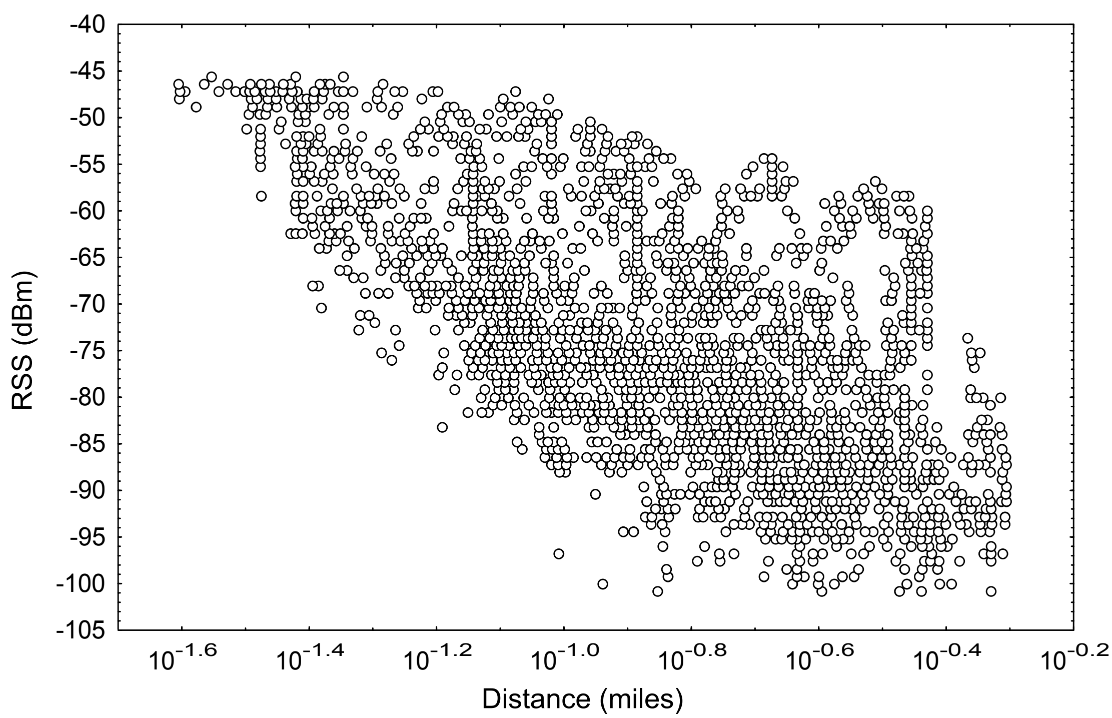


Figure 7.17. Downlink received signal strength (RSS) vs. distance (TAG 3, microcell site 11).

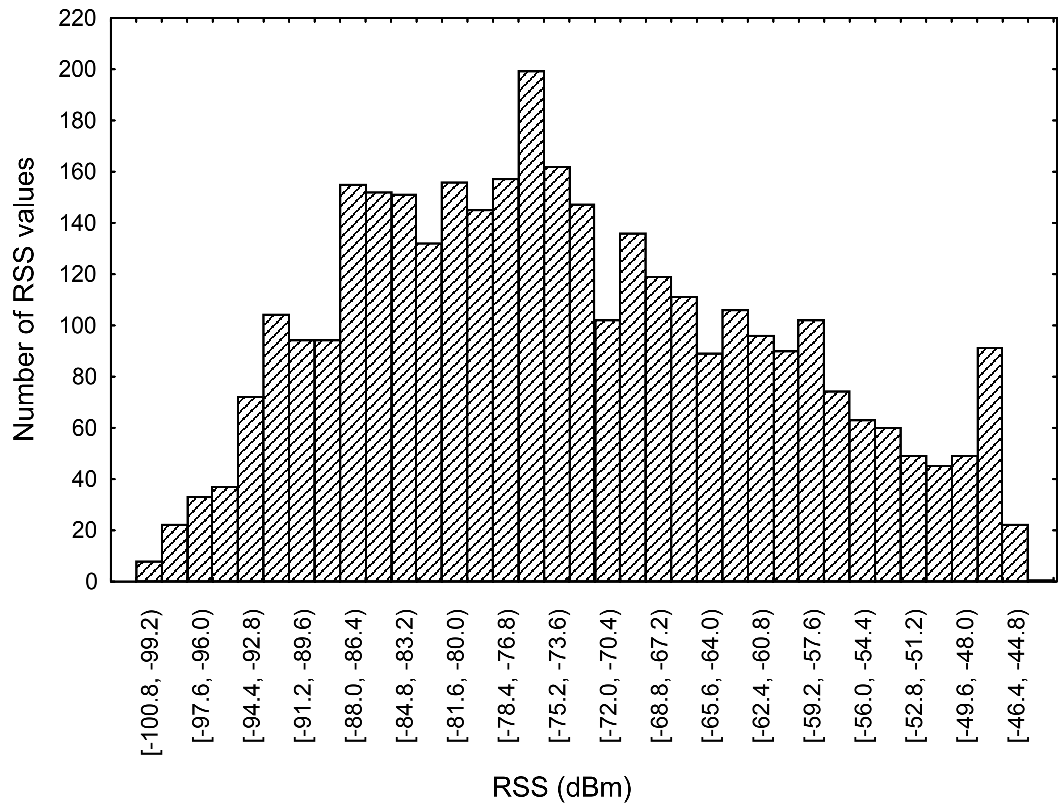


Figure 7.18. Histogram of downlink received signal strength (RSS; TAG 3, microcell site 11).

7.3.5 Link Balance Analysis for Combined Microcell Sites

For the link balance analysis, the data for Sites 1, 3, 9, and 11 were combined into a single file. The data were then analyzed to generate separate plots of average uplink and downlink WER as a function of RSS.

In generating the average uplink WER vs. RSS plot, the uplink RSS values were rounded to an integer value. For a particular uplink RSS value, all corresponding uplink WER values were averaged. The same procedure was repeated for all available uplink RSS values greater than -118 dBm. The result of this analysis is represented in Figure 7.22. As expected, in general, as the RSS is increased, the WER decreases.

The same methodology used in generating the average uplink WER vs. RSS plot was used to generate the average downlink WER vs. RSS plot except that RSS values less than -101 dBm were not included. The resulting plot of average downlink WER vs. RSS is shown in Figure 7.23. Here, also as expected, the WER decreases as the RSS increases.

By comparing Figures 7.22 and 7.23, note that the corresponding RSS for a given WER is different between the uplink and downlink. As an example, for a 10% WER, the RSS on the uplink is -98 dBm and on the downlink is -91 dBm.

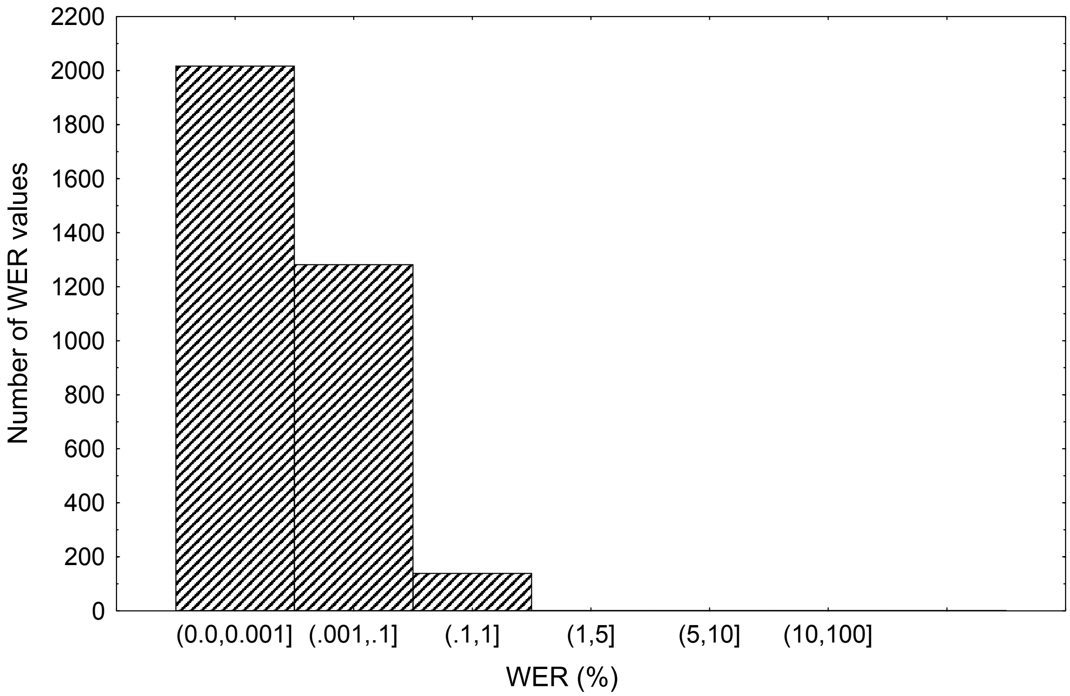


Figure 7.19. Histogram of downlink word error rate (WER; TAG 3, microcell site 11).

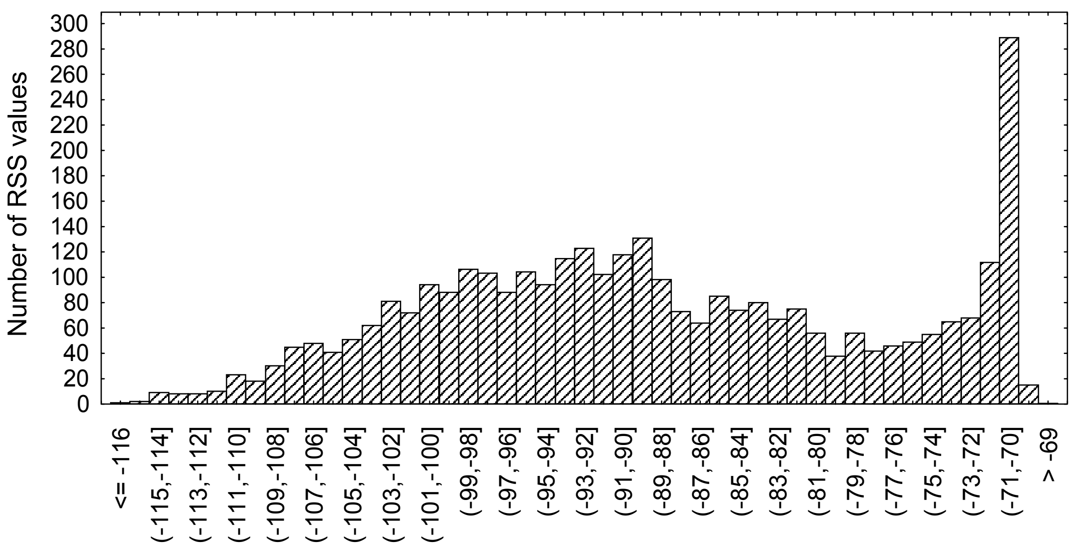


Figure 7.20. Histogram of uplink received signal strength (RSS; TAG 3, microcell site 11).

To determine if the link was balanced, and if not, to estimate the amount of link unbalance, a histogram of the difference between the downlink and uplink RSS was generated. This histogram is shown in Figure 7.24. The mean difference between downlink and uplink RSS is 14.46 dB with a standard deviation of 5.60 dB. In other words, the RSS at the base station was typically weaker than the RSS at the mobile unit.

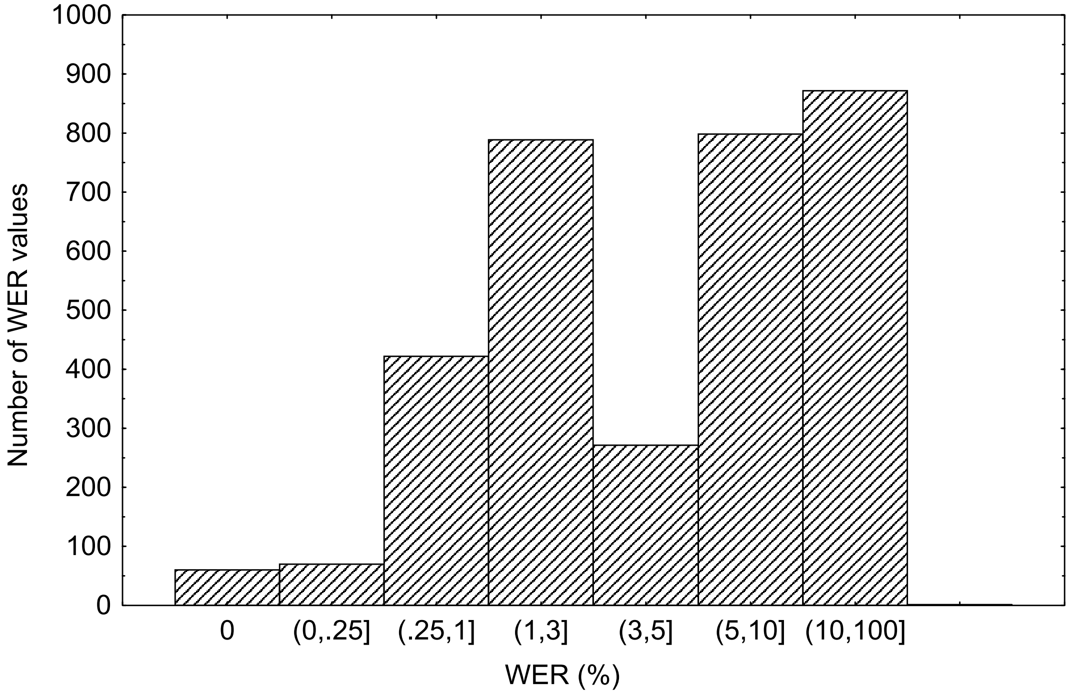


Figure 7.21. Histogram of uplink word error rate (WER; TAG 3, microcell site 11).

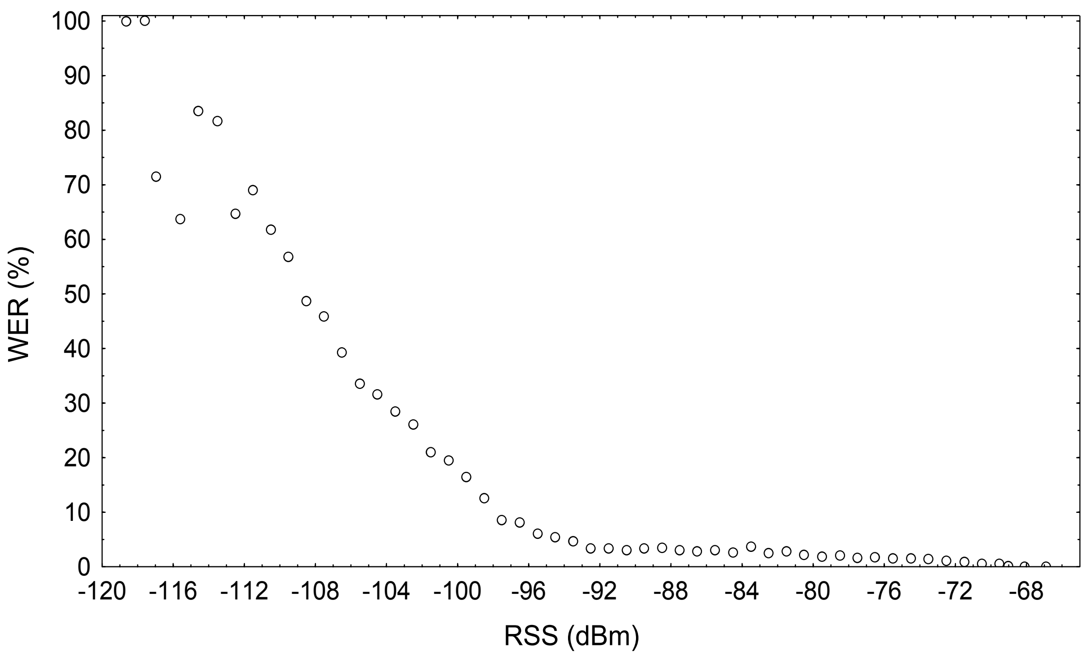


Figure 7.22. Average uplink word error rate (WER) vs. received signal strength (RSS; TAG 3).

One way of determining if the system is uplink or downlink limited is to compare the WER's between the uplink and downlink. The procedure to compare the WER's between the two

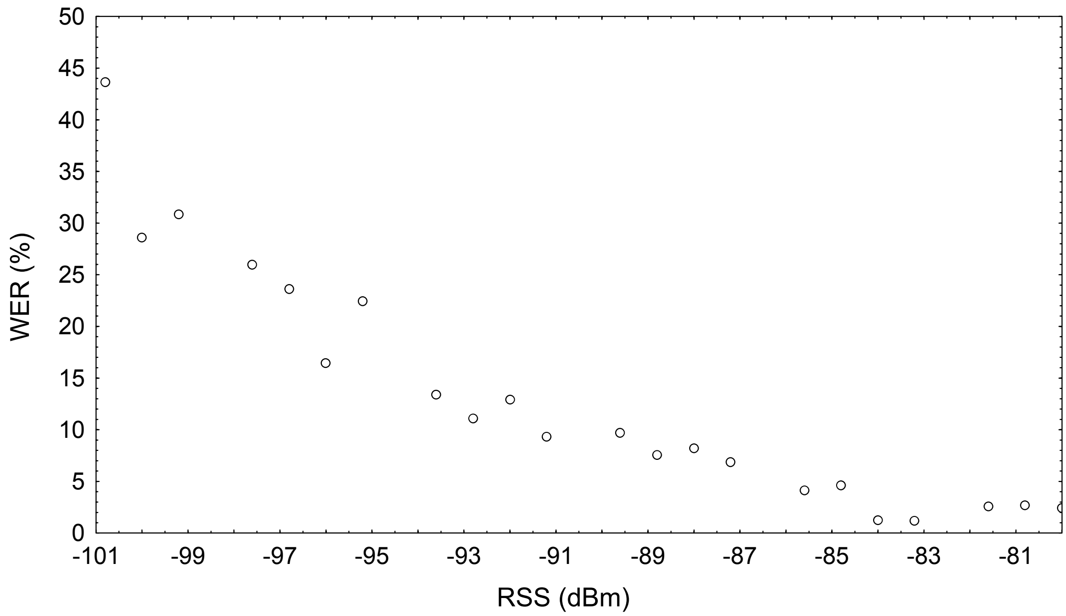


Figure 7.23. Average downlink word error rate (WER) vs. received signal strength (RSS; TAG 3).

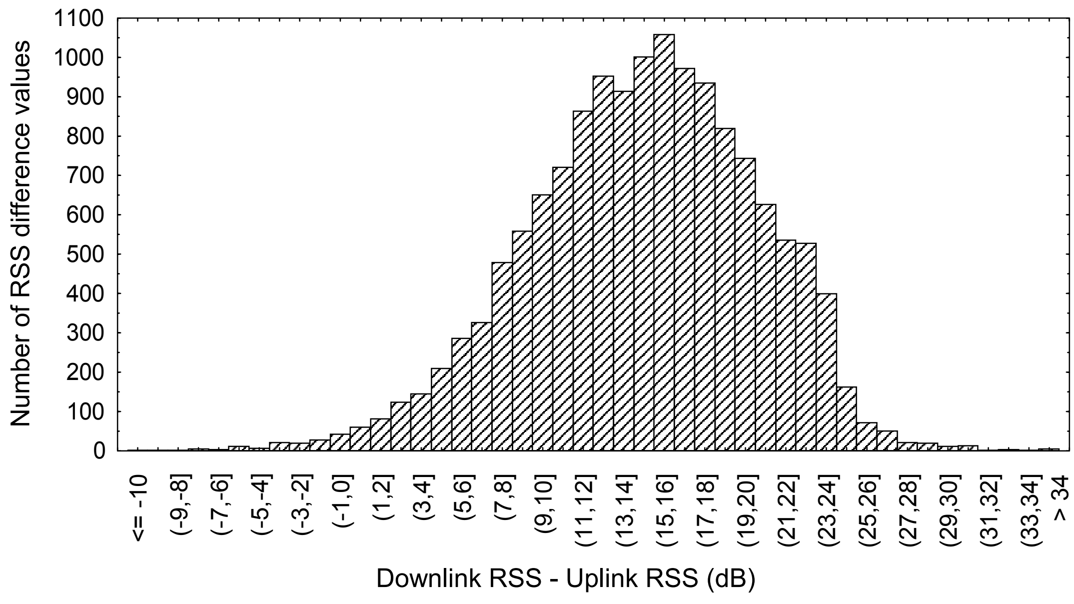


Figure 7.24. Histogram of difference between downlink and uplink received signal strength (RSS; TAG 3).

links is best illustrated with an example. First select a specific downlink RSS such as -92 dBm. The corresponding downlink WER, found from Figure 7.23, is 13%. Now to compare this to the corresponding uplink WER, recall that there is a difference between the downlink and uplink RSS. Using the mean difference between the downlink and uplink RSS values, an uplink RSS of -106.5 dB corresponds to the downlink RSS of -92 dBm used in this example. Using the uplink RSS value of -106.5 dBm in Figure 7.22, an uplink WER of 39% is obtained. Therefore the uplink WER (39%) is larger than the corresponding downlink WER (13%). Repeating this analysis for any other RSS value yields the same result: the uplink WER is consistently higher than the downlink WER. Therefore, the system is uplink limited.

7.4 Handoff Testing

The TAG 3 PACS technology was designed to support low-speed (up to 35 mph) handoff. As per JTC requirements, the low-speed handoff testing was performed. The low-speed handoff testing was conducted in downtown Boulder. In addition to low-speed handoff testing, high-speed handoff testing was performed in south Boulder as an optional test. The purpose of the high-speed handoff testing was to determine handoff functionality for speeds greater than 35 mph.

Low-speed handoff testing was performed by pushing a cart containing the mobile unit at pedestrian speeds along chosen routes in downtown Boulder. All four microcells used in the area coverage testing were used here. All four microcells were activated and handoff was allowed between the microcells. The routes were chosen to maximize the number of handoffs between the microcells. Typically, a call was initiated within a block of a base station, and the data (objective measures such as RSS, WER, and time) were collected as the measurement cart was pushed along the sidewalk of a street toward a particular base station. The uplink and downlink objective measures were recorded at the same time. A measurement run was considered completed when the mobile unit went out of the coverage area and the call was dropped. Although a typical measurement run consisted of only one handoff between two base stations, some runs had multiple handoffs between more than two base stations, due to the choice of a particular route, base station configuration, and propagation environment.

Three types of handoff parameters were determined from the data analysis:

1) the difference between RSS before and after handoff,
2) the difference between WER before and after handoff, and
3) the time between two successive handoffs.

Table 7.1 shows the values of these parameters for all of the handoffs recorded during the low-speed handoff testing. There were a total of 31 handoffs recorded during 14 measurement runs. All values were calculated based on readings taken immediately before and after an individual handoff occurred (a 1-s difference).

Table 7.1 shows that 16 out of the 31 handoffs had no changes in both the RSS and WER readings before and after handoff. This is unusual, since handoff is initiated when either the RSS or WER deteriorate significantly with respect to the RSS or WER readings from neighboring base stations. There was one instance when both the RSS and WER had worse readings after handoff than before handoff. In three other cases, either the RSS or the WER had a worse reading after handoff than before handoff. In six cases, both the RSS and WER improved after a handoff.

Table 7.1 also shows that the minimum time between successive handoffs was 13 s. This implies that no ping-ponging occurred during the handoff testing. Recall that ping-ponging was defined in Section 3.4 as a rapid sequence of handoffs between cell sites and/or sectors.

The high-speed handoff measurements were made in south Boulder. Three base stations (at Sites 17, 18, and 19) were activated for this testing. The output of each base station transmitter was set to provide an EIRP of 6.3 W. The mobile unit was mounted inside a measurement van with its antenna mounted on the roof of the vehicle. Measurements were taken as the measurement van traveled along Broadway near the Table Mesa shopping center. A separate measurement run was made in the northbound direction and then in the southbound direction at each of the following speeds: 20, 30, 40, 50, and 60 mph. For the southbound measurement runs, calls were initiated with the measurement van close to Site 17 (Broadway and Hanover Street). For the northbound measurement runs, calls were initiated with the measurement van close to Site 19 (Broadway and Grinnell Street). After initiation of the call, data were collected as the measurement van traveled in the specified direction. Both uplink and downlink data were collected for each measurement run.

The handoff data for the 40-mph case showed that coverage was provided by each base station when the measurement van was in the vicinity of that base station. The coverage area for each base station was roughly centered about each base station. On the other hand, at 60 mph, the coverage area for each base station was shifted in the direction opposite of the direction that the measurement van was traveling. Therefore, at 60-mph speeds, coverage was affected. This implies that special consideration would be needed in the cell layout plan to support up to 60-mph handoff while not necessarily needed to support handoff up to 35 or 40 mph.

7.5 Interference Testing

The interference testing consisted of both co-channel and adjacent channel interference measurements. The interference measurements for this system, however, differed from the interference measurements of the other JTC PCS technologies. The interference measurements for the PACS TAG 3 system were made indoors under stationary conditions. The operation of the PACS TAG 3 system was not suited for outdoor interference measurements. All of the interference measurements for the PACS TAG 3 system were conducted inside the building on the 3rd floor at the WCO. The base station located at Site 3 was used as the intended source. A signal generator, located on the 3rd floor of the building at the WCO, was used as the interfering signal. In addition, the mobile unit was located on the same floor of the building. While this setup was not ideal because the indoor measurement reduced the shadowing, it was the best possible under the given conditions.

As explained before, these measurements differ from the outdoor measurements because less log-normal shadowing is encountered, but they do give insight on how C/I affects WER.

For the co-channel interference measurements, the transmitters for both the intended source and the interferer were set to 1971.5 MHz. The RSS of the intended source measured at the mobile unit (downlink) was -63 dBm. The level of the interfering signal was changed manually, by adjusting the power output of the signal generator. The interfering signal's

Table 7.1. Handoff Parameter Data

Handoff Number	RSS after - RSS before handoff (dB)	WER before - WER after handoff (%)	Time between successive handoffs (s)
1	2	2	80
2	0	2	140
3	0	0	39
4	0	0	14
5	0	0	38
6	0	0	28
7	-2	0	77
8	0	0	56
9	0	0	36
10	0	3.75	81
11	5	0.25	150
12	0	4	87
13	0	0	37
14	2	-0.25	47
15	-2	2	75
16	19	2.5	53
17	0	0	13
18	-2	-1.25	46
19	0	1.25	68
20	14	1.75	56
21	5	0	116
22	4	6.75	40
23	0	0	52
24	0	0	80
25	0	0	51
26	0	0	88
27	1	0.25	50
28	0	0	42
29	0	0	38
30	0	0	26
31	0	0	28

power was adjusted so that the RSS at the mobile unit was -93 dBm. The level of the interfering signal was increased until the WER started showing non-zero values. While the goal was to show WER (as reported by the mobile unit) as a function of C/I, only the C/I threshold where the WER became non-zero could be readily identified. For the co-channel interference case, when the C/I was greater than 9 dB, the WER was zero. When the C/I was less than 9 dB, the WER was greater than zero.

For the adjacent channel interference measurements, the transmitter for the intended source was set to 1971.5 MHz. The transmitter for the interferer was set to 1971.8 MHz. As for the co-channel interference measurements, the RSS of the intended source measured at the mobile unit (downlink) was -63 dBm. The level of the interfering signal was changed manually, by adjusting the power output of the signal generator. The interfering signal's power was adjusted so that the RSS at the mobile unit was -78 dBm. The level of the interfering signal was increased until the WER started showing nonzero values. As in the co-channel interference measurements, WER as a function of C/I for adjacent channel interference could not be obtained, only the C/I threshold where the WER became nonzero could be readily identified. For the adjacent channel interference case, when the C/I was greater than -17 dB, the WER was zero. When the C/I was less than -17 dB, the WER was greater than zero. As expected, a much lower adjacent channel C/I than co-channel C/I is required to keep the WER zero.

7.6 Voice Quality

As discussed in Section 3.6, two types of voice quality measurements were made for the PCS JTC technology field trials in general: quasi-stationary measurements and handoff measurements. Both types of measurements were performed for the PACS (TAG 3) technology.

7.6.1 Quasi-stationary Measurements

Voice recordings and various objective measures including uplink and downlink RSS and uplink and downlink WER were collected at locations 100 m (approximately one block) apart around Site 1 and Site 3. Measurements were taken at the 62 specific locations shown on the map in Figure 7.25. A total of 120 measurements were taken because both uplink and downlink measurements were taken at most but not all of the locations. Only one microcell was activated at a time. At each location, data were collected as the measurement cart was pushed at a pedestrian speed in a 10-m circle for the duration of the sample time. The same sample time was used for each location. The measurements were taken at each location by establishing a call between the mobile and landline telephones. While the measurement cart was in motion, an audio source tape was transmitted over the radio link in both the uplink and downlink directions simultaneously. The source tape transmitted over each link was the same as that used for TAG 5 testing (see Section 3.6.1).

The received voice transmissions were recorded on digital audio tape at the receiver for the uplink and downlink simultaneously. The recorded voice segments were then digitized with 16-bit resolution at a 22-Ksample/s rate and stored on a hard disk drive. At each location, the objective measures including uplink and downlink RSS, uplink and downlink WER, and GPS time and location were collected every second at the same time as the voice recordings were made.

For the quasi-stationary measurements, voice quality of the voice segments was determined by both mean opinion score (MOS) and expert listener techniques. The following sections discuss these techniques and present the results based on the application of these techniques.

7.6.2 Mean Opinion Score Assessment

To accomplish the MOS testing, a pool of 36 subjects was recruited from the Boulder, Colorado area. Each of the following age groups were represented within the subject pool: 18-25, 25-35, 35-45, 45-55, and those over 55 years of age. There were 14 male and 17 female subjects. The subjects were cordless, noncellular telephone users.

Three groups consisting of eight subjects each and one group consisting of seven subjects were formed from the subject pool. The subjects were asked to rate voice segments by answering the three questions listed in Section 3.6.2 after each segment was presented.

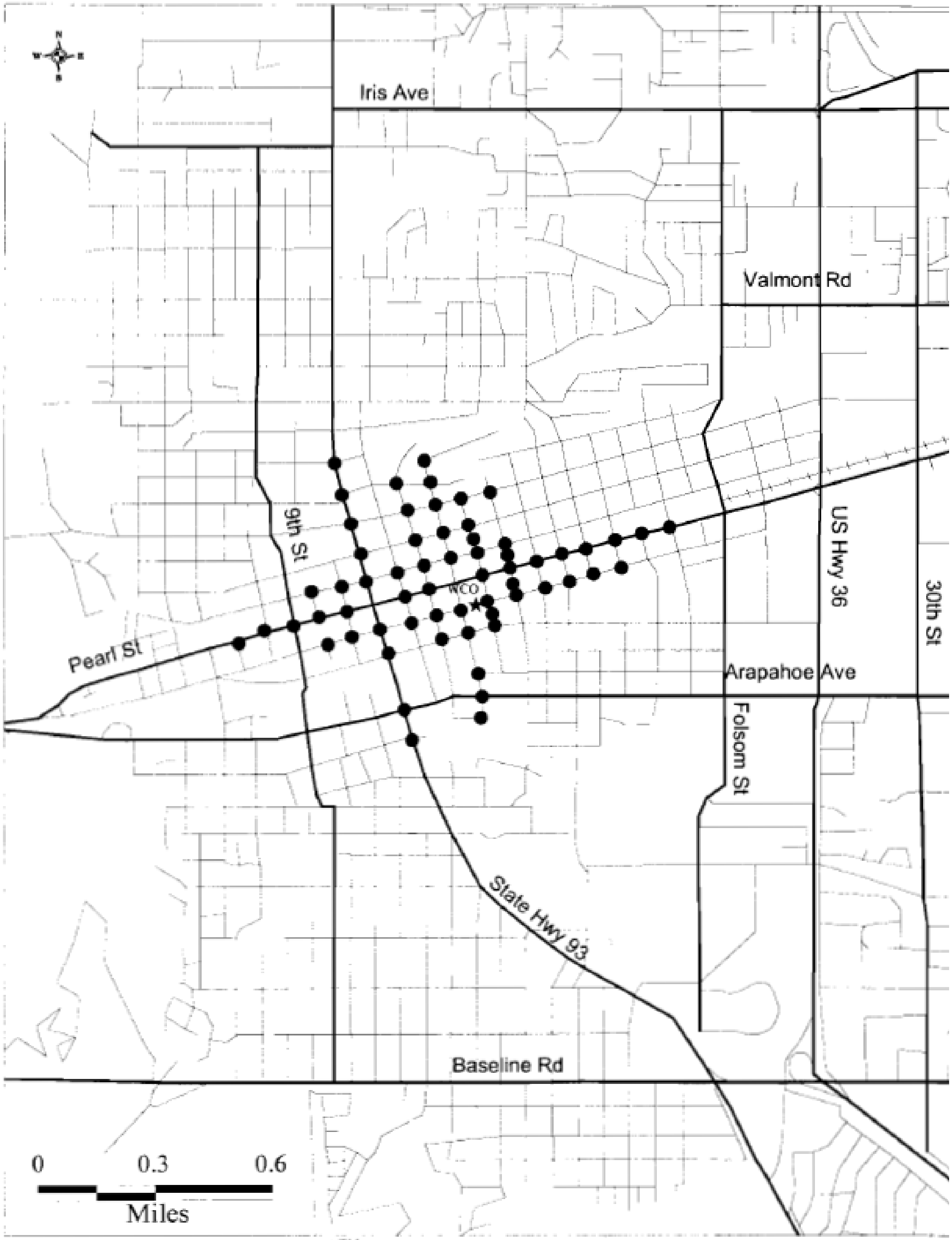
First, the subjects in each of the four groups were presented 10 practice voice segments to rate. The practice segments were exactly the same as the ones used for TAG 7 testing. The description for these is given in Section 6.6.2.

After the practice segments were presented, the subjects in each of the four groups were asked to rate 33 voice segments: 3 reference voice segments and 30 voice segments from the field trial measurements. Every listener within a group listened to the same voice segments. The reference voice segments consisted of one 64-kbps wireline voice segment and two voice segments collected from field measurements (one with a definitely acceptable expert listener rating and one with an unacceptable expert listener rating). The 30 voice segments from the field trial measurements came from the uplink or downlink measurements at a portion of the 62 measurement locations. The number and type (male or female) of sentences that were used and the order in which they were used to form a voice segment are the same as that described in Section 4.6.2. Subjects were given two breaks during each session. After all segments were presented, subjects filled out a post-trial questionnaire.

For each voice segment, voice quality ratings (answers to the question "How would you rate the overall quality of the sound?") from each subject within a group were averaged to obtain an MOS. The results from all four of the groups, from a total of 120 voice segments are shown in the histogram in Figure 7.26. Overall, the voice segments were rated favorably, with 88% of the segments rated between fair and excellent. The average MOS was 3.68 and the standard deviation was 0.70.

Figures 7.27 and 7.28, show histograms of MOS's for the uplink and downlink, respectively. The average MOS for the uplink was 3.91 and for the downlink was 3.41. Note that the distributions of MOS are quite different for the uplink and downlink. The uplink histogram shows a larger spread in MOS's with higher maximum MOS's and lower minimum MOS's than the downlink histogram. A t-test revealed that there is a statistically significant difference in the average MOS's between the uplink and downlink.

The relationship between the MOS's and some of the objective measures was initially investigated by generating some scatter plots. Figure 7.29 shows the relationship between the MOS's and average RSS for both the uplink and downlink combined. For RSS values between approximately -92 and -70 dBm, a large variation in MOS's is seen. Much less variation in MOS's is seen for RSS values above approximately -70 dBm. For RSS values below approximately -92 dBm, the MOS's tend to degrade rapidly.



Maps made with MapInfo Professional ™

Figure 7.25. Quasi-stationary measurement locations for TAG 3.

Figures 7.30 and 7.31 show the relationship between the MOS's and the average WER for both the uplink and downlink, respectively. Both the uplink and downlink show some variation in MOS for a given RSS. The uplink shows a relationship between high MOS's and low WER; however, the downlink does not show this relationship.

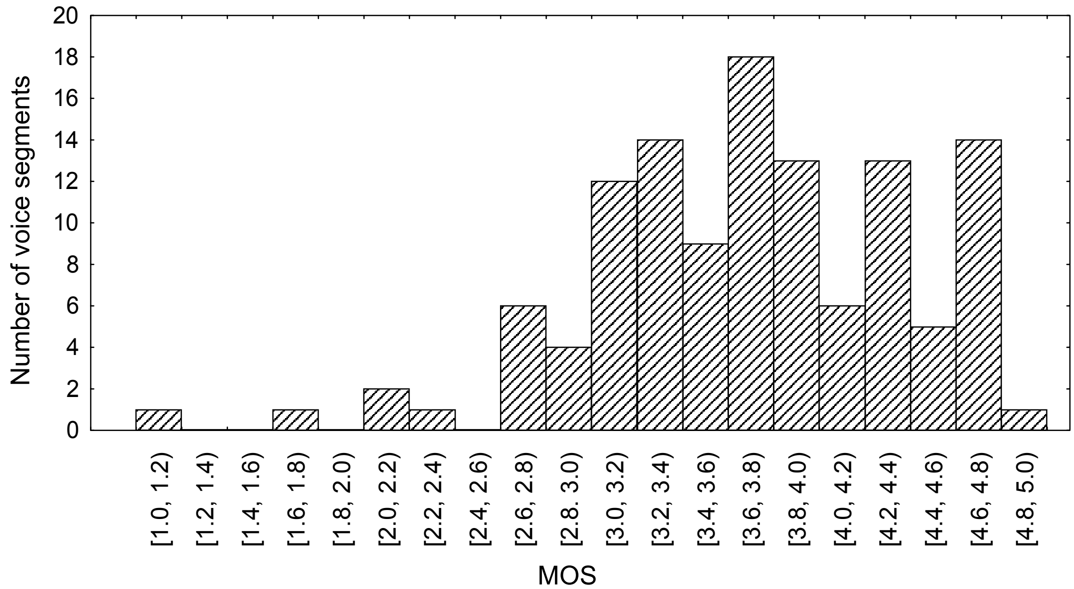


Figure 7.26. Histogram of mean opinion scores (MOS's) for all voice segments (TAG 3).

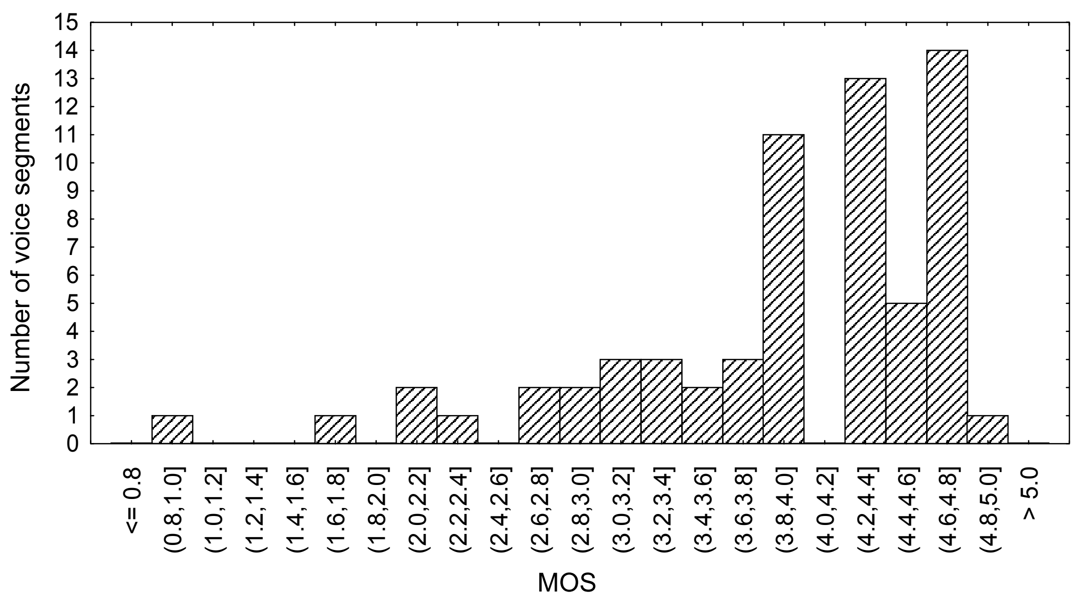


Figure 7.27. Histogram of uplink mean opinion scores (MOS's; TAG 3).

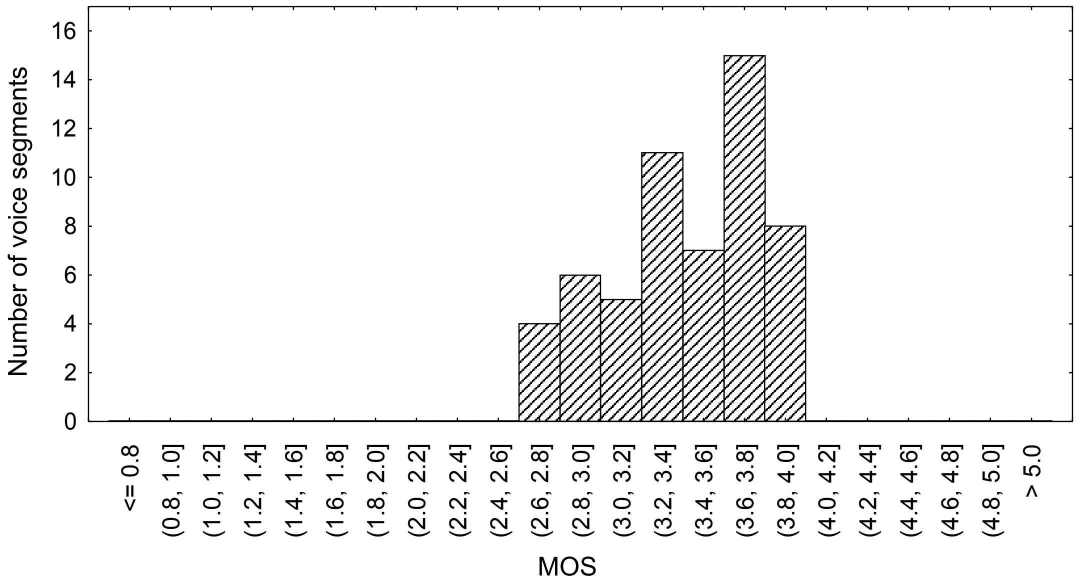


Figure 7.28. Histogram of downlink mean opinion scores (MOS's; TAG 3).

Pearson product-moment correlations were performed to determine the correlation between MOS's and average RSS and MOS's and average WER. These correlations were performed for the data on the uplink first and then for the data on the downlink. For the uplink, the correlation coefficient between MOS and average RSS was 0.63 and that between MOS and average WER was -0.55. These correlation coefficients between MOS and averaged objective measures suggest that a strong linear relationship between MOS and the objective measures on the uplink does not exist. The correlation coefficient between the average RSS and the average WER for the uplink was -0.40. A higher correlation between these measures was expected.

While there does not appear to be a strong linear relationship between MOS and the objective measures for the uplink, there still may be a strong consistently increasing or decreasing relationship between them. The Spearman rank correlation can be used to determine if a consistently increasing or decreasing trend may exist between MOS and the objective measures. For the uplink, Spearman rank correlations were performed to determine the correlation between the ranks of MOS and the ranks of average RSS and between the ranks of MOS and the ranks of average WER. The Spearman rank correlation coefficient between MOS and average RSS was 0.65 and that between MOS and average WER was -0.78. These rank correlations between MOS and averaged objective measures are higher than the Pearson product-moment correlations. The rank correlation between MOS and average WER is significantly higher than the Pearson product-moment correlation. This suggests that the consistently increasing or decreasing relationship between MOS and WER is stronger than the linear relationship between MOS and WER.

For the downlink, the correlation coefficient between MOS and average RSS was 0.48 and that between MOS and average WER was -0.05. These correlation coefficients suggest that while there is some linear correlation between MOS and average RSS there is very little linear correlation between MOS and average WER. A strong linear relationship between MOS and the objective measures on the downlink does not exist. The correlation coefficient between the average RSS and the average WER for the downlink was -0.14. A higher correlation between these measures was expected.

For the downlink, Spearman rank correlations were performed to determine the correlation between the ranks of MOS and the ranks of average RSS and between the ranks of MOS and the ranks of average WER. The Spearman rank correlation coefficient between MOS and average RSS was 0.55 and that between MOS and average WER was -0.25. These rank correlations between MOS and averaged objective measures are higher than the Pearson product-moment correlations. This suggests that the consistently increasing or decreasing relationship between MOS and the objective measures is stronger than the linear relationship between MOS and the objective measures.

Note that as in the data analysis of the previous JTC PCS technologies (TAG 5, TAG 2, TAG 4, and TAG 7), the objective measures were averaged over the entire length of the voice segment. By analyzing the instantaneous variation or possibly minimum and maximum values of the objective measures within the voice segment, further insight may be gained on the behavior of MOS's.

By gathering listeners' comments from post-test questionnaires, more information about the nature of MOS's was obtained. Namely, it is evident from questionnaires that there are several types of distortions in quality possible in the TAG 3 voice segments according to listeners:

1) "static,"
2) "background noise," and
3) "popping noises."

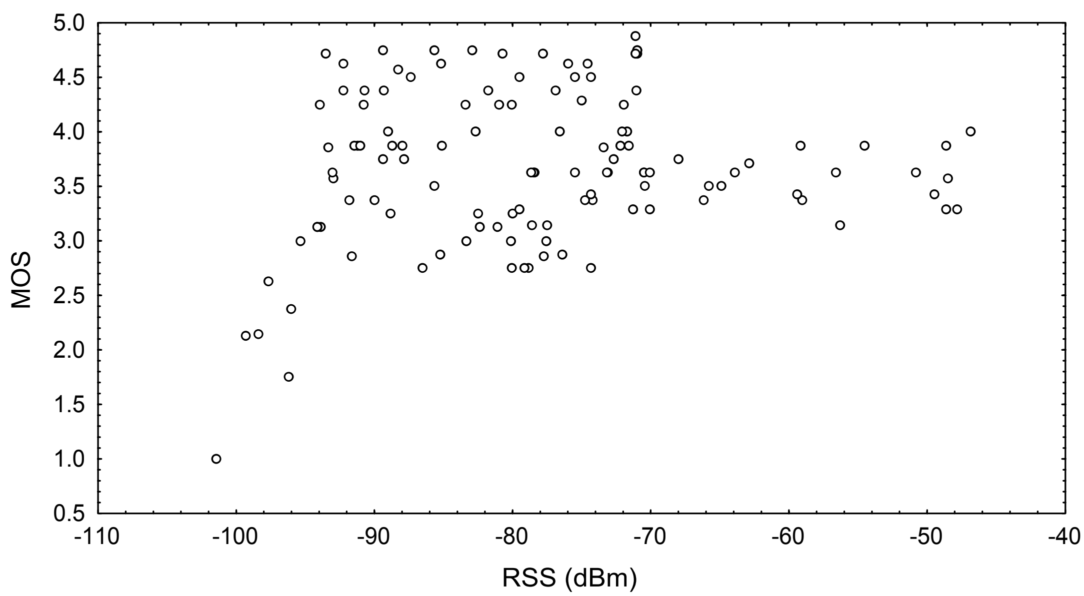


Figure 7.29. Mean opinion score (MOS) vs. average received signal strength (RSS; TAG 3).

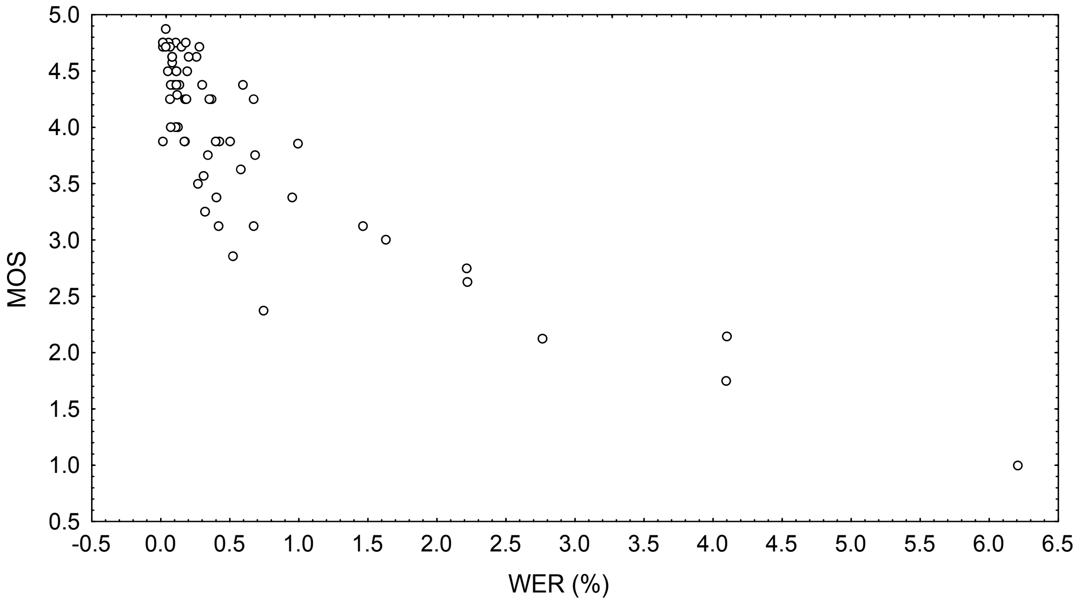


Figure 7.30. Mean opinion score (MOS) vs. average uplink word error rate (WER; TAG 3).

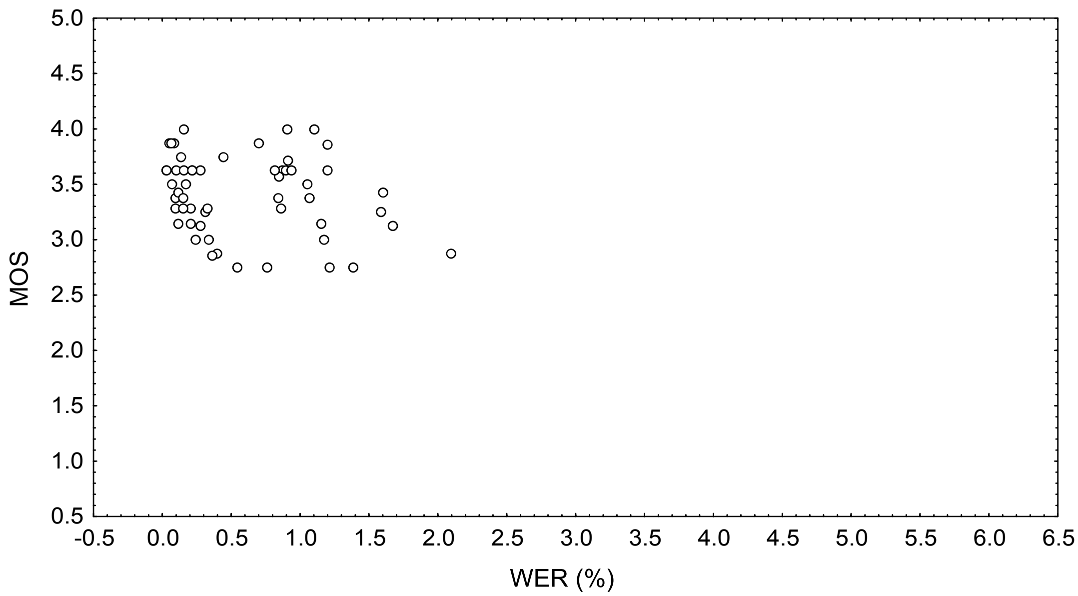


Figure 7.31. Mean opinion score (MOS) vs. average downlink word error rate (WER; TAG 3).

These types of distortions are the exact words used by listeners. The nature of these distortions are likely judged differently by different listeners. Intelligibility and speaker recognition are two main aspects of perceived quality. For most of the voice samples, intelligibility remained high. As a result, overall MOS's were high.

7.6.3 Expert Listener Assessment

In addition to being rated by listener panels in MOS testing, the voice segments were rated by an expert listener.[14] The expert listener ratings followed the identical procedure as in the PCS 1900 (TAG 5) testing. This procedure is described in Section 3.6.3.

Figure 7.32 shows the relationship between expert listener ratings and percent acceptability (the percentage of listeners rating a given voice segment as acceptable). The boxes represent the middle half of the data (from the 25th percentile to the 75th percentile). The solid circles represent the median percent acceptabilities for each of the expert listener ratings. The lines extending out of the boxes depict the spread of the data.

The expert listener ratings were very good indicators of percent acceptability for the voice segments in the TAG 3 testing. The expert listener ratings accurately predicted the percent acceptability for 114 out of the 120 voice segments recorded.

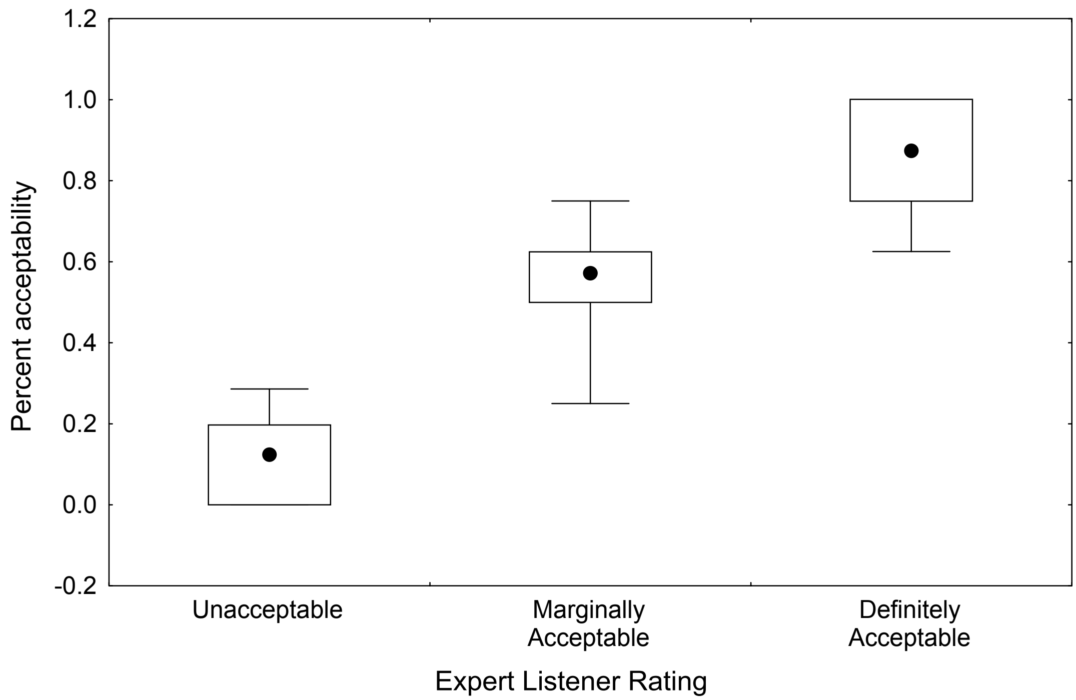


Figure 7.32. Percent acceptability vs. expert listener rating (TAG 3).

The Pearson product-moment correlation coefficient between MOS and percent acceptability was 0.87; this number indicates a strong correlation between these measures, as would be expected. The Pearson product-moment correlation coefficient between MOS and expert listener rating was 0.75; this number indicates a fairly strong correlation between these measures. The Pearson product-moment correlation coefficient between percent acceptability and expert listener rating was 0.90; this number indicates a strong correlation between these measures.

[14] A new expert listener was trained and rated voice segments for the TAG 7 and subsequent JTC PCS technology field trials (TAG 3 and TAG 1). The original expert listener rated voice segments for all of the JTC PCS technology field trials prior to TAG 7 (TAG 5, TAG 2, and TAG 4).

7.6.4 Voice Quality Handoff Measurements

Voice recordings of transmitted voice signals were made during the low-speed handoff testing that was described in Section 7.4. These voice recordings were made simultaneously on the uplink and downlink at the same time as the other handoff data (objective measures described in Section 7.4) were collected. Data were collected as the measurement cart was pushed at a pedestrian speed during 14 measurement runs.

For the voice quality handoff testing, an expert listener rating was made for each 4-s period of the continuous voice recordings taken along each measurement run. Voice quality remained acceptable for the uplink over the length of each measurement run, with no degradation until the call was dropped. None of the uplink handoffs were distinguishable to the expert listener. Voice quality was primarily acceptable for the downlink over the length of each measurement run, however 8 of the 14 measurement runs did have brief periods (less than 3 s) of marginally acceptable voice quality. These periods were not associated with handoffs. None of the downlink handoffs were distinguishable to the expert listener.

Voice quality measurements were also made during the optional high-speed handoff testing. Voice recordings of transmitted voice signals were made as the measurement van traveled along Broadway as described in Section 7.4. An expert listener rating was made for each 4-s period of the continuous voice recordings taken along each measurement run. On the uplink, voice quality remained acceptable for the duration of each measurement run with no degradation until the call was dropped. On the uplink, approximately 28% of the handoffs were distinguishable to the expert listener as a 200- to 400-ms period of muting. The remaining uplink handoffs were not perceptible to the expert listener at all.

On the downlink, 40% of the measurement runs had voice quality degradation as the call approached the edge of coverage. Approximately 50% of the downlink handoffs were perceptible by the expert listener as a 200- to 400-ms period of muting. The remaining downlink handoffs were not perceptible to the expert listener at all.

7.7. Manufacturers' Statements

Statements provided by the manufacturers involved in the testing are included in this section. These statements are identical to those given in [6], except for some minor editorial changes.

7.7.1 Motorola, Inc.

The PACS development team from Motorola believes the primary BITB trial objectives to record range, voice quality, and handoff performance were successfully completed. The trial results indicate the low-tier, low-power PACS system has good range, excellent voice quality, and nearly indiscernible handoff characteristics. Additionally, the initial high-speed test results indicate the PACS standard may have very good wireless telephony performance even in this demanding environment. Antenna diversity both at the radio ports (base stations) and subscriber (mobile) units along with the short frame rate helps improve performance for all of these parameters.

Motorola would like to thank U S West Advanced Technologies for providing the facilities to perform the required tests and ITS for their participation in the calibration and test phases of the trial. More importantly, Motorola would like to thank the U S West Advanced Technologies personnel for their support in getting the PACS system up and functional in such a short time. Finally, Motorola would like to acknowledge the cooperation from the NEC and Matsushita engineering teams in helping Motorola polish the last few remaining system issues that subsequently facilitated a very successful field trial.

7.7.2 NEC

NEC would like to thank U S West Advanced Technologies and ITS for all of their hard work in the BITB field trial in Colorado. NEC believes that the achievement of the trial was due to their great efforts. NEC would further like to acknowledge the support and cooperation from the Motorola and Panasonic development teams during the trial. NEC was pleased to provide the infrastructure for the trial of the PACS radio air interface in the BITB. The subscriber (mobile) units were provided by Motorola and Panasonic.

As can be seen from this section of the report and the visitor's day demonstrations, the PACS system performed quite well. The trial results indicate the PACS system has good coverage, pure natural voice quality, and excellent handoff functionality. In particular, high-speed handoff test results show that the PACS radio air interface has enough capability to support mobile communications in all environments.

Finally, NEC deeply acknowledges all TAG 3 participants including Hughes Network Systems, Pacific Communication Sciences, Inc., Hitachi, and Lucent Technologies for their efforts in completing the JTC standardization process for the PACS air interface. Special thanks are extended to Bellcore for their contribution.

7.7.3 Panasonic

Panasonic would like to recognize the efforts of all the TAG 3 members and supporters in the successful completion of the PACS field trial in Boulder, Colorado. The trial satisfied the JTC requirement to use working equipment in the field to verify the standard. Although not required, equipment was supplied by multiple manufacturers demonstrating interoperability of PACS equipment.

The TAG 3 trial was the first to use the low-tier cell sites in downtown Boulder, Colorado and the surrounding residential areas. At these locations, the system demonstrated good range and excellent voice quality in a heavily obstructed environment. In addition, the high-speed testing at the Table Mesa site indicated no degradation at vehicular speeds (60 mph) and handoff was successfully verified as well with no discernible speech interruption.

These results demonstrate that PACS can provide good coverage and high mobility while maintaining the advantages of its microcell architecture. Also, the interoperability demonstrated among equipment from different vendors only a few months after the standard was approved is a good indication of the lower complexity of PACS and the completeness of the standard. It is also a testament to the efforts of all of the TAG 3 members.

Panasonic would like to thank U S West Advanced Technologies for making the BITB facilities available for these tests. Panasonic sincerely appreciates the efforts of J. Corliss and the entire U S West Advanced Technologies team for the long hours and hard work in making the field trial successful. Panasonic would also like to thank ITS for their participation as the independent observer collecting data and monitoring the tests, and Anritsu for supporting the equipment calibration. In addition, Panasonic thanks NEC and Motorola for their help and support in making the PACS field trial successful. It could not have happened without the cooperation and team effort given by all of the participants.

8. TAG 1 (COMPOSITE CDMA/TDMA SYSTEM) TESTING

This section describes the test plan, methodology, and results for the technology field trial conducted by TAG 1. The technology tested was the PCS composite CDMA/TDMA IS-661 standard. All of the radio equipment, including the base stations and the mobile units, were provided by Omnipoint Corporation. The telephony portion of the system was a Meridian system supplied by Nortel. The TAG 1 field tests examined area coverage, handoff, and voice quality, and the effects of co-channel and adjacent channel interference on system performance.

The information presented in this section is taken from [7]. The reader is referred to [7] for a more complete and detailed presentation of the TAG 1 technology field testing at the BITB.

8.1 TAG 1 Test System Configuration

Two different test system configurations were used for the TAG 1 field technology testing: a high-tier configuration using three cell sites and a low-tier configuration using a single microcell site.

A block diagram of the high-tier test system configuration is shown in Figure 8.1. This test system consisted of three cell sites in Boulder, Colorado (WCO, TMCO, and GMM) and a Nortel Meridian M1 network controller. The Meridian M1 network controller was located at the WCO and was connected to the three WCO base stations (one for each sector). The two GMM base stations (one for each active sector) were connected to the network controller via an LOS microwave link with a D4 channel bank on each end of the link. The LOS microwave link was used to provide a partial T1 link between the GMM base station and the WCO base station. A T1 connection between the TMCO base station and the network controller was provided by a fiber optic link with a SONET add/drop multiplexer and D4 channel bank on each end of the link. The base station transmit frequencies used during the high-tier testing for each cell site and sector are given in Table 8.1. Four antennas, used for both transmitting and receiving, were employed during high-tier testing for every sector in every cell.

For the low-tier testing, a single microcell (Site 3, located at the intersection of Pearl Street and 15th Street in downtown Boulder) was used. The base station was mounted on a traffic light pole 24 ft above the street level. Two 6-dBi omnidirectional antennas used for both transmitting and receiving were employed.

8.2 Calibration

Calibration of the mobile unit used in the TAG 1 field trial consisted of checking the accuracy of the RSS values reported. This was done by injecting a digitally modulated signal of known level into the mobile unit's receiver and comparing this signal level with the RSS value reported by the mobile unit. The input signal into the mobile unit receiver was provided by the base station through a coaxial cable and fixed and variable step attenuators. Losses through the coaxial cable and attenuators were measured. A correction, or offset, was added to the signal power output by the base station to obtain the signal level input into the mobile unit's receiver. The level of the injected signal at the mobile unit's receiver was varied from -65 to -95 dBm in 5-dB steps to find the difference between the actual RSS and the RSS reported by the mobile unit's receiver. The maximum difference was found to be 2.7 dB. Another part of the calibration procedure entailed measuring the base station transmit power. The results of this procedure, however, are not presented in this report.

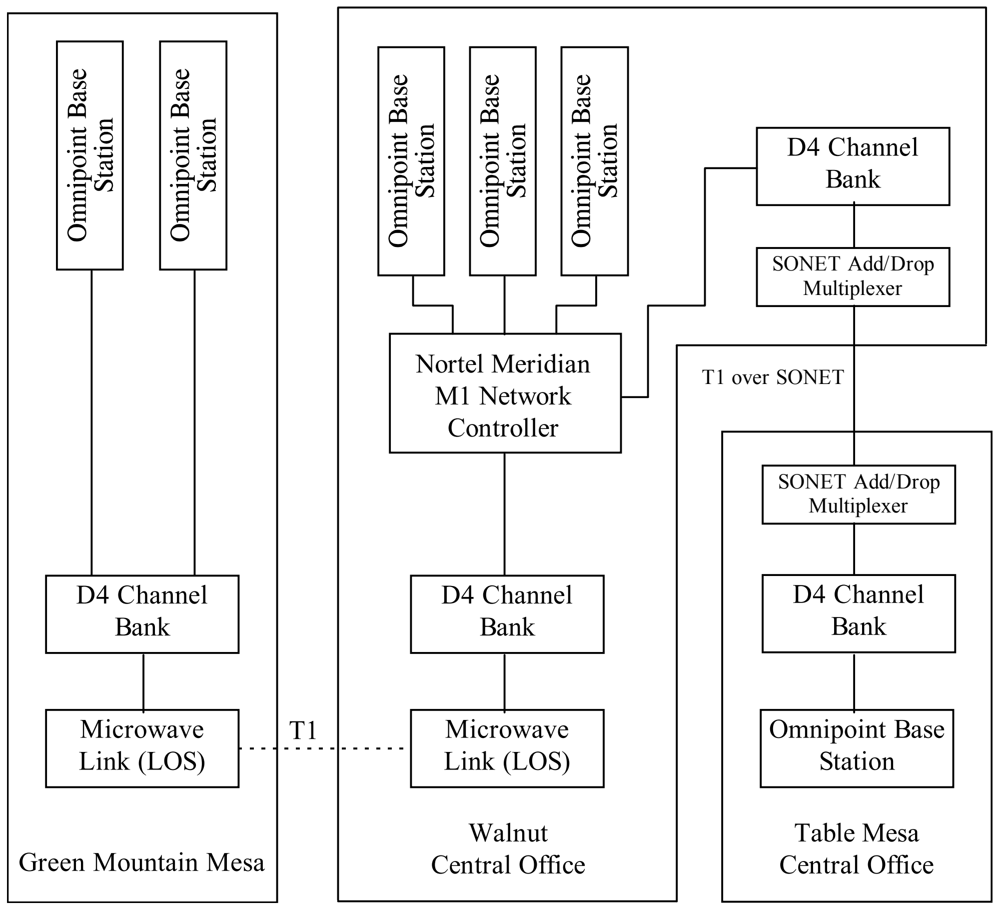


Figure 8.1. Block diagram of the TAG 1 test system configuration.

Table 8.1. Base Station Transmit Frequencies

Cell Site	Sector	Operating Frequency (MHz)
WCO	North	1871.875
WCO	Southeast	1883.125
WCO	Southwest	1877.500
GMM	North	1873.750
GMM	Southeast	1957.500
TMCO	North	1963.125

8.3 Area Coverage Testing

The area coverage testing for TAG 1 included the three high-tier cell sites and the one low-tier microcell site. The nominal EIRP for each cell site is listed in Table 8.2. The nominal EIRP for each cell site is found by averaging the transmit power into every antenna for every sector in the cell and then adding the nominal antenna gain.

Table 8.2. Nominal Radiated Power for Each Cell Site

Cell Site	Nominal EIRP (dBm)
GMM	44.4
TMCO	47.5
WCO	48.0
Site 3 (Low Tier Site)	31.0

The mobile unit transmitter used a nominal EIRP of 26.7 dBm for the high-tier testing and a nominal EIRP of 25.8 dBm for the low-tier testing.

Measurements to show area coverage were taken with the mobile unit[15] located in a mini-van as in the previous field trials. Four passengers were allowed in the vehicle. The mobile unit was mounted inside the van on the same wooden structure used in all of the JTC PCS technology field trials. This structure is described in Section 3.3. For the low-tier microcell, an antenna mounted on the roof of the measurement van was used. The measurements were taken by driving along routes (radials) away from the cell site. When time permitted, measurements along additional routes in between the radials were taken. Vehicle speed was limited to 35 mph or less for the low-tier testing.

Only one cell site was activated at a time during area coverage testing; all other cell sites were powered down. Handoff was allowed between the sectors of the active cell. The data were collected both at the mobile unit (downlink) and at the base station (uplink) simultaneously during the same measurement run at the TMCO cell site. Because of both time and measurement equipment constraints, for all other high-tier cell sites and the low-tier microcell site, the data were collected only at the mobile unit (downlink). The data collected at the mobile unit included GPS location and time, downlink RSS, average downlink BER, and other system parameters. The data collected at the base station included GPS time and location and average uplink BER. Uplink RSS values were not collected for the TAG 1 testing.

Calls were originated at the beginning of a measurement route prior to the start of data collection. Collection of mobile data and base station data was initiated as the measurement van began traveling away from the cell site along the drive route. At the end of the route, the data collection was stopped and the data were saved to disk. For the low-tier cell, the point along the

[15] Measurements in the GMM cell were also taken with an antenna mounted on the roof outside of the mini-van. For purposes of brevity and because it was not a formal part of the JTC PCS technology field trials, the measurements performed with the antenna located out of the measurement van for the GMM cell during area coverage testing are not discussed in this NTIA report.

route where the call was dropped marked the end of the coverage test for that particular route. All analyzed data for the area coverage testing represented the average of measured data taken over a 300-ft interval for the high-tier testing and taken over a 60-ft interval for the low-tier testing. Each individual measurement was triggered by a 3-ft vehicle movement.

For determining the area coverage boundaries in a cell, a minimum acceptable RSS needed to be defined. A minimum acceptable RSS was determined by first combining all of the downlink data from all of the high-tier cells and the low-tier microcell. Downlink RSS values were rounded off to the nearest integer. For each given integer downlink RSS value greater than -100 dBm, all of the corresponding BER values were averaged. Figure 8.2 shows a plot of the average downlink BER vs. RSS.

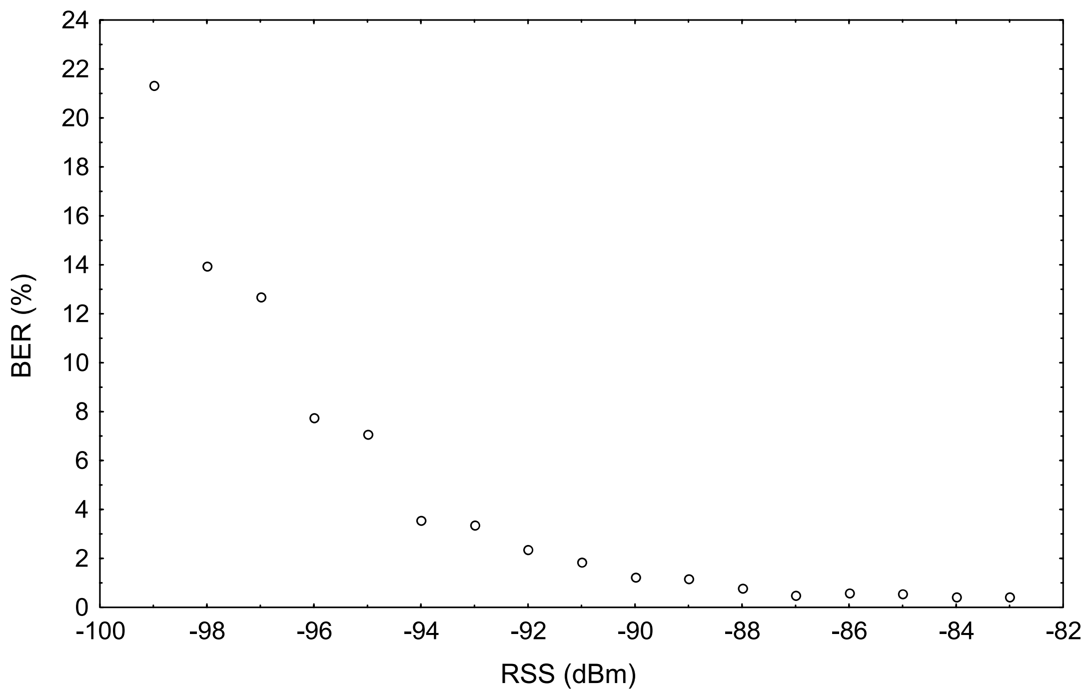


Figure 8.2. Average downlink bit error rate (BER) vs. received signal strength (RSS) for all high-tier cells and the low-tier microcell (TAG 1).

By defining a maximum acceptable average BER value and using Figure 8.2, a minimum acceptable RSS for area coverage could be determined. A maximum acceptable average BER of 5% was chosen because average BER values greater than 5% are very likely to imply unacceptable voice quality. Therefore, from Figure 8.2, a minimum acceptable RSS of -95 dBm was chosen (corresponding to a BER of 7%) as an area coverage threshold. This threshold value was used to determine area coverage for all of the high-tier cells and the low-tier microcell.

8.3.1 TMCO Area Coverage Data

The test procedure followed and data collection methodology used are explained in Section 8.3. Only the north sector was active for this cell site.

Downlink RSS as a function of distance is shown in Figure 8.3. The data included in this figure are the overall data for this cell with -100 dBm being the lowest recorded RSS. The large variation in RSS seen in Figure 8.3 is due to the irregularity of the terrain. Note that relatively strong signals (approximately -84 to -86 dBm) existed far away from the cell (approximately 5 mi). Those signals were recorded in areas having LOS propagation between the mobile unit and the base station.

A rough estimate of the coverage area was determined by assuming that an RSS of -95 dBm or greater is desired. The measured RSS data along all of the routes driven within the cell were used to determine the coverage area. Due to the irregularity of the terrain, the RSS varied significantly along the TMCO routes, crossing the -95 dBm level several times before finally staying below -95 dBm. The point along each route where the RSS first dropped below -95 dBm was used to define the coverage boundaries. For this case, the coverage boundaries were approximately 0.76 mi northwest, 2.1 mi northeast, and 2.15 mi east.

Figure 8.4 shows the histogram of downlink RSS values. The mean RSS was -91.6 dBm with a standard deviation of 11.3 dB.

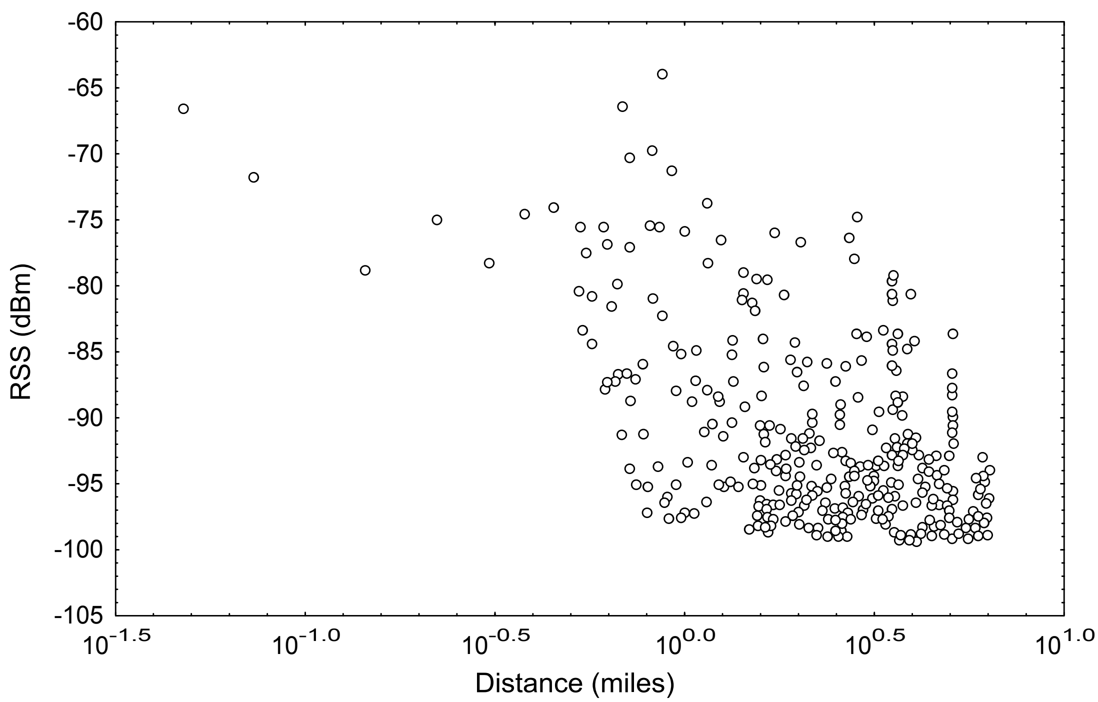


Figure 8.3. Downlink received signal strength (RSS) vs. distance (TAG 1, TMCO cell).

The downlink average BER histogram is shown in Figure 8.5. Approximately 42% of all downlink data points had an average BER less than 1%. Figure 8.6 shows the uplink average BER histogram. For the uplink, approximately 65% of the data points had an average BER less than 1%.

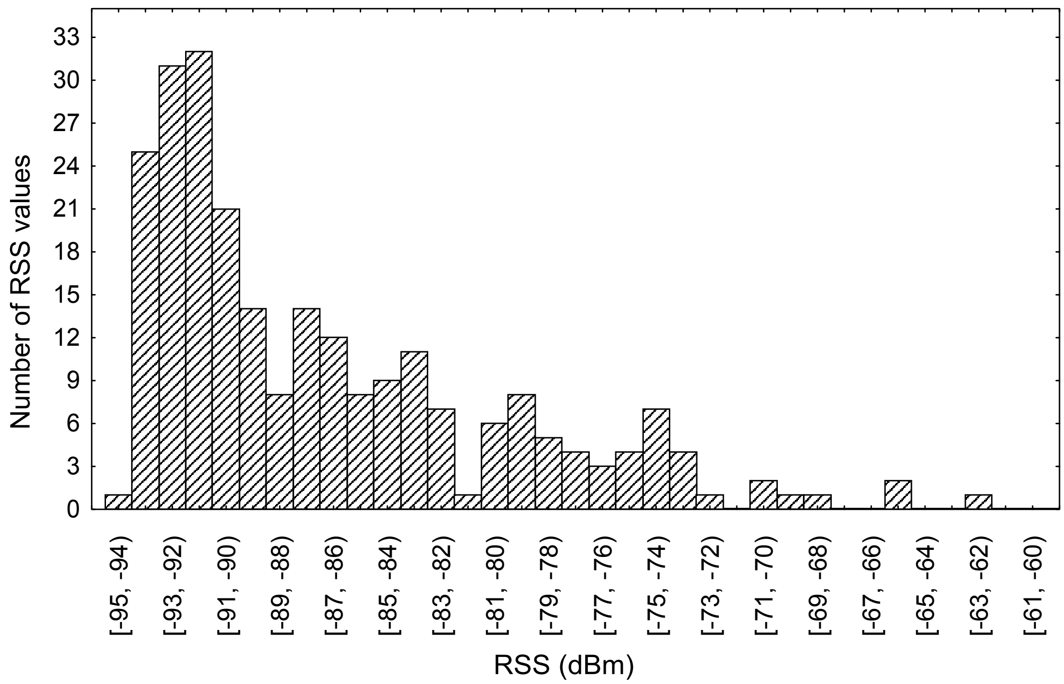


Figure 8.4. Histogram of downlink received signal strength (RSS; TAG 1, TMCO cell).

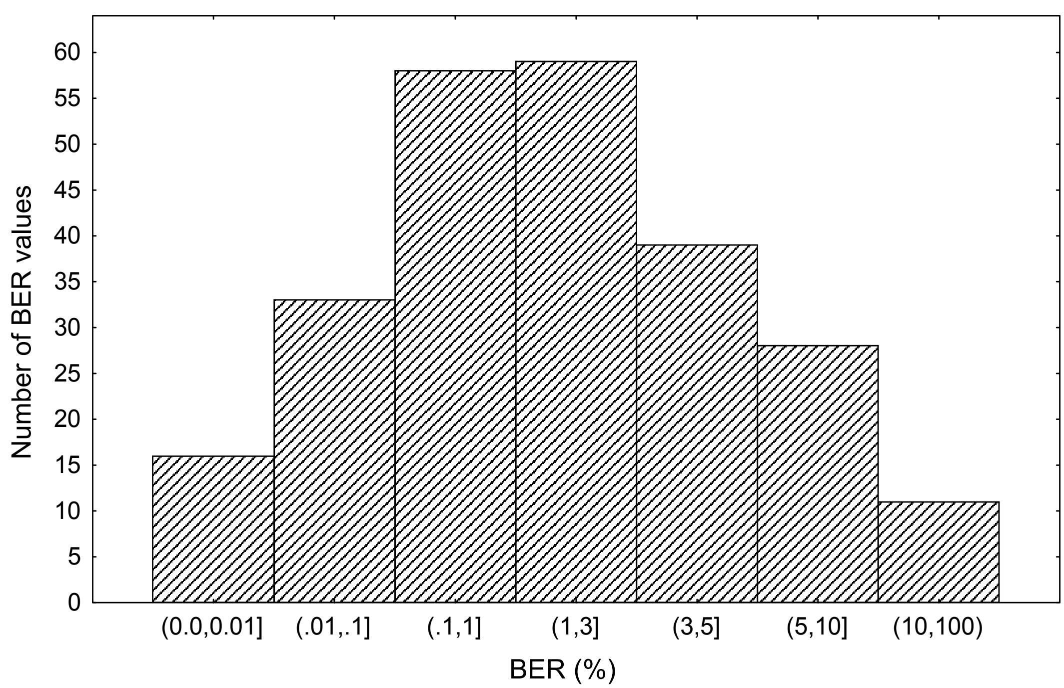


Figure 8.5. Histogram of average downlink bit error rate (BER; TAG 1, TMCO cell).

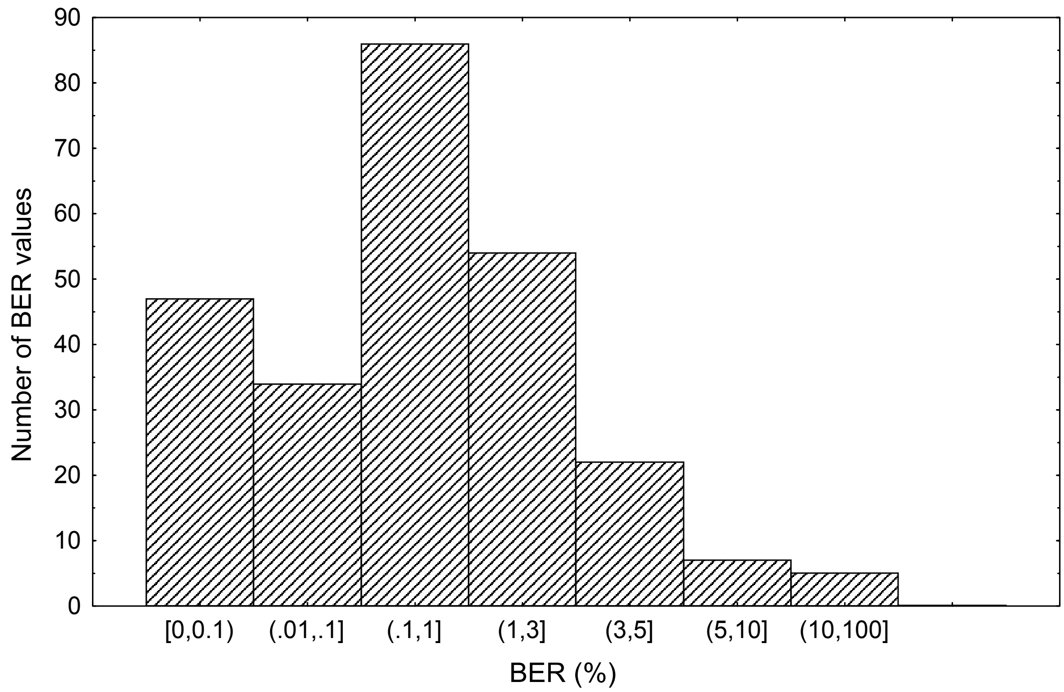


Figure 8.6. Histogram of average uplink bit error rate (BER; TAG 1, TMCO cell).

A link balance analysis was performed to determine if the uplink and downlink were balanced, and if not, which link was weaker. The presence of severe imbalance may contribute to a higher BER at the weaker link, and thus limit coverage in a cell.

The link balance analysis was performed for the TMCO cell only since the TMCO cell was the only one to record both uplink and downlink average BER. BER data for both links were taken simultaneously. The difference between average downlink and uplink BER values was computed. The histogram showing this difference is given in Figure 8.7. While data points with an RSS less than -95 dBm were excluded from the coverage area analysis, they were included in the link balance analysis. The mean difference between average downlink BER and uplink BER (average downlink BER given as a percentage minus average uplink BER given as a percentage) is 7.41%; the standard deviation is 9.93%. Therefore, the system was downlink limited.

8.3.2 WCO Area Coverage Data

The test procedure followed and data collection methodology used are explained in Section 8.3. All three sectors were active for this cell site. Downlink RSS as a function of distance is shown in Figure 8.8. The data included in this figure are the overall data for this cell with -100 dBm being the lowest recorded RSS. As in the TMCO cell, there is a large variation in RSS values for a given distance. This variation is caused by shadowing and the choice of the measurement routes. Note that a strong signal (approximately -60 dBm) exists approximately 1.8 mi away from the cell site. Comparing the downlink RSS vs. distance plots between the

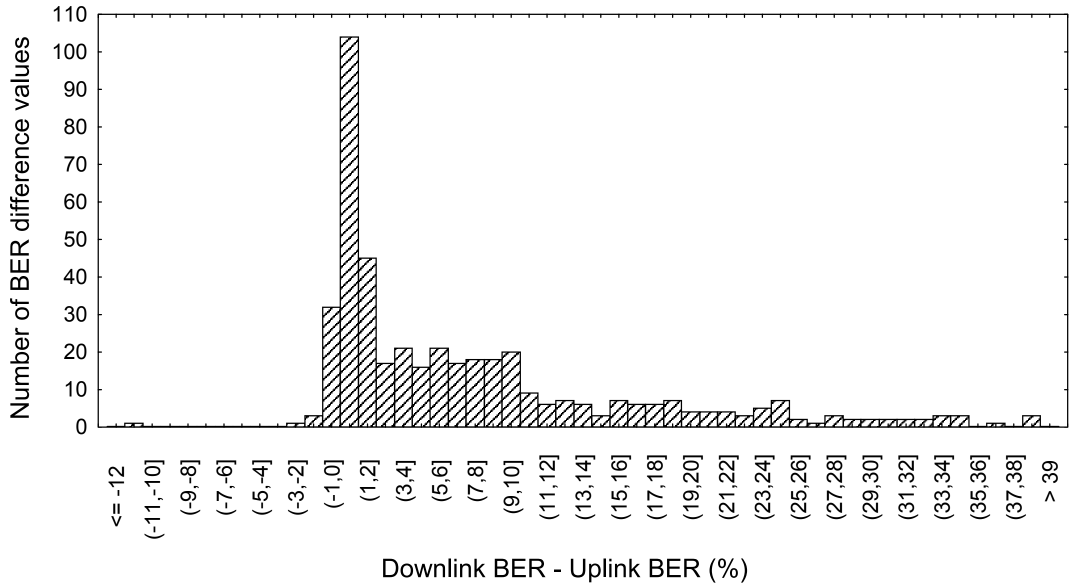


Figure 8.7. Histogram of difference between average downlink and uplink bit error rate (BER; TAG 1, TMCO cell).

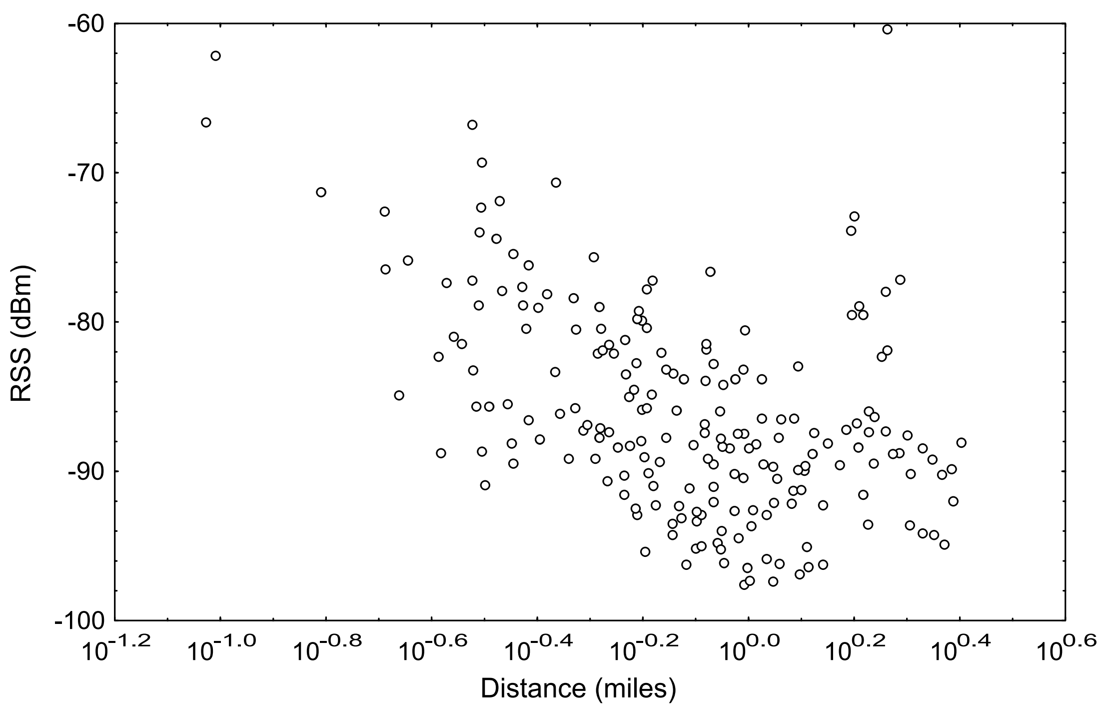


Figure 8.8. Downlink received signal strength (RSS) vs. distance (TAG 1, WCO cell).

WCO and TMCO cells (Figures 8.2 and 8.8) suggests that the WCO cell has a smaller coverage area than the TMCO cell.

A rough estimate of the coverage area was determined by assuming that an RSS of -95 dBm or greater is desired. The measured RSS data along all of the routes driven within the cell were used to determine the coverage area. For this case, the coverage boundaries were approximately 0.9 mi to the northwest, 1.85 mi to the east, and 0.74 mi to the west. Once the RSS fell below -95 dBm in these directions, it generally stayed below -95 dBm. Because of the lower elevation of the WCO cell site (relative to the TMCO cell site) and the terrain profile, the WCO cell had a smaller coverage area than the TMCO cell.

Figure 8.9 shows the histogram of downlink RSS values for the WCO cell. The mean RSS was -86 dBm and the standard deviation was 16 dB.

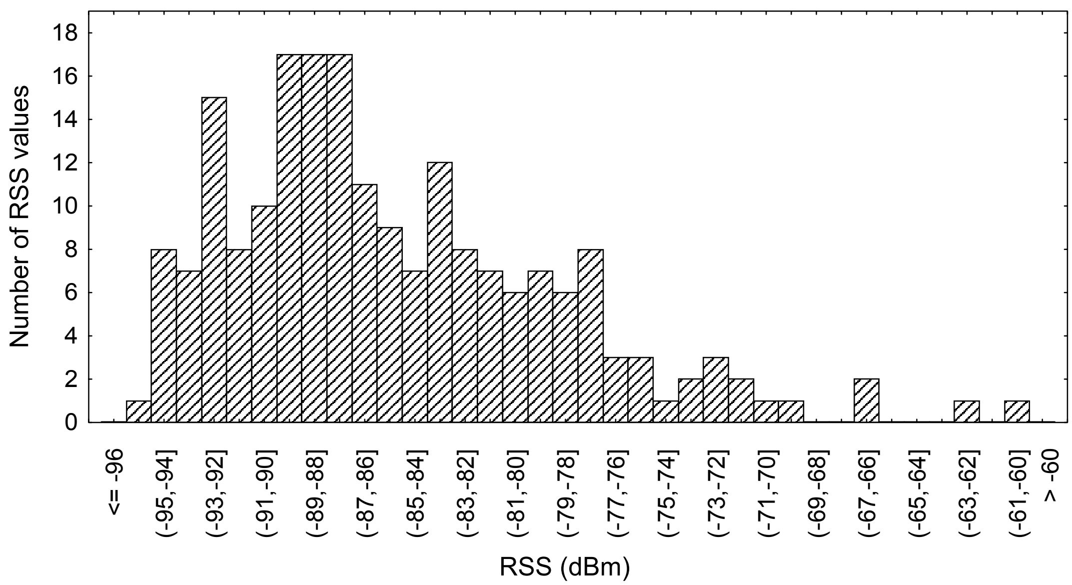


Figure 8.9. Histogram of downlink received signal strength (RSS; TAG 1, WCO cell).

The downlink average BER histogram is shown in Figure 8.10. For the downlink, approximately 70% of all data points had an average BER less than 1%. (Recall that average uplink BER was collected at the TMCO cell only.)

8.3.3 GMM Area Coverage Data

As for the TMCO and WCO area coverage testing, the test procedure followed and data collection methodology used are explained in Section 8.3. As mentioned in Section 8.3, for the GMM cell, measurements were made with an antenna mounted on the roof of the measurement van and with the antenna inside the vehicle. A penetration loss analysis was performed using the results from the measurements made with the antenna both inside and outside of the vehicle.

For the sake of brevity and because they were not a formal part of the JTC testing, the measurements made with the antenna mounted on the roof in the GMM cell and the penetration loss analysis are not discussed in this report. Two sectors (the northeast and southeast sectors) were active for this cell site.

Downlink RSS as a function of distance is shown in Figure 8.11. The data included in this figure are the overall data for this cell (in-vehicle antenna only) with -100 dBm being the lowest recorded RSS. As in the TMCO and WCO cells, there is a large variation in RSS

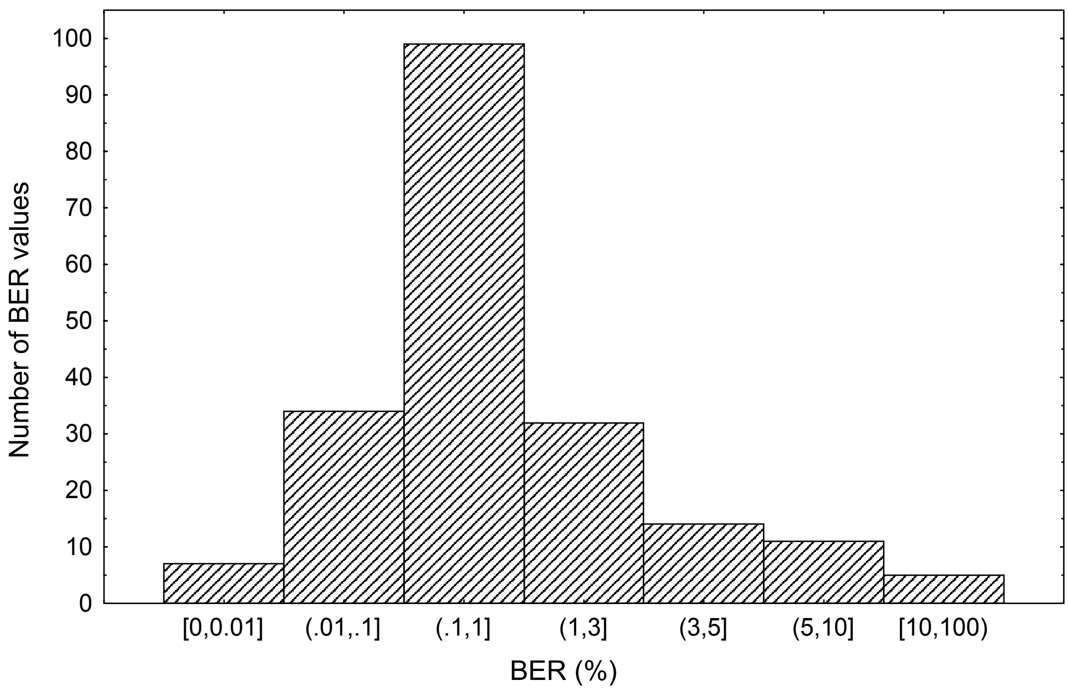


Figure 8.10. Histogram of average downlink bit error rate (BER; TAG 1, WCO cell).

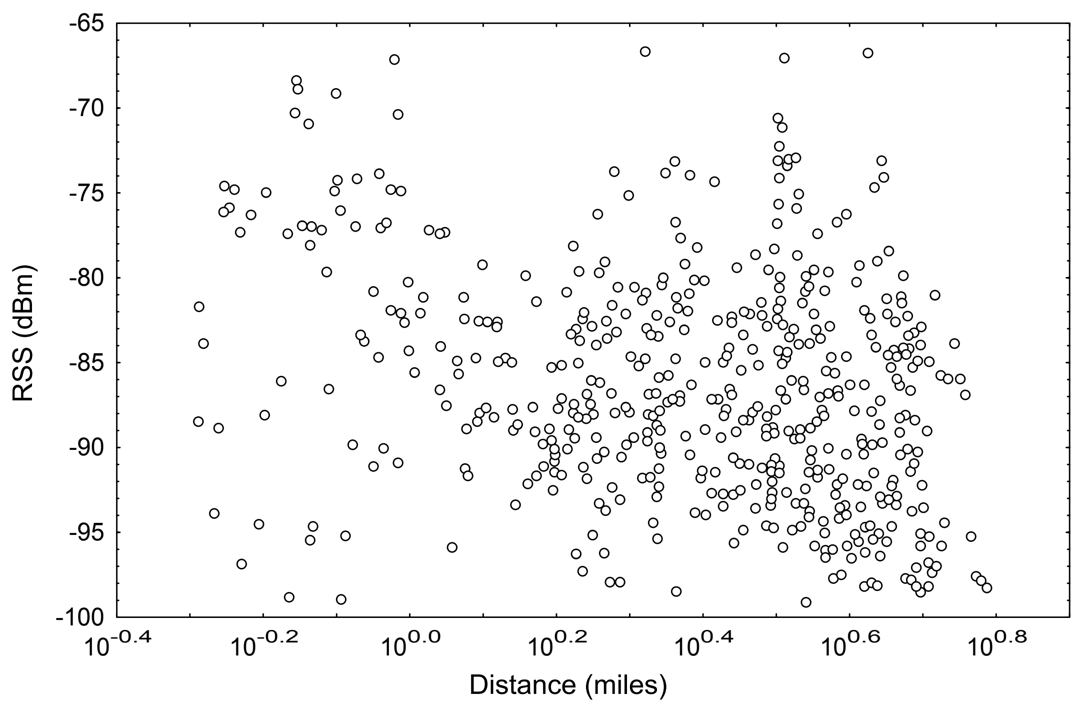


Figure 8.11. Downlink received signal strength (RSS) vs. distance (TAG 1, GMM cell).

values for a given distance. This variation is caused by large differences in the environment and terrain in the different areas where measurements were taken for this cell. To the northeast and east, the environment was mostly residential with less terrain obstructions than to the north. To the north, the environment was mostly light urban. Relatively strong signals as high as -81 dBm were measured as far as 5 mi from the cell site to the east.

A rough estimate of the coverage area was determined by assuming that an RSS of -95 dBm or greater is desired. The measured RSS data along all of the routes driven within the cell were used to determine the coverage area. For this case, the coverage boundaries were approximately 3.7 mi to the north, 5.5 mi to the east, 4.9 mi to the northeast, and 4.5 mi to the southeast. Because of the significantly higher elevation of the GMM cell site than the other two cell sites, good coverage was seen to the north, east, and southeast. Coverage to the south was poorer than in the other directions because of the terrain profile.

Figure 8.12 shows the histogram of downlink RSS values for the GMM cell. The mean RSS was -85.2 dBm and the standard deviation was 11.2 dB. The large standard deviation is caused by large differences in the environment and terrain in the different areas where measurements were taken for this cell.

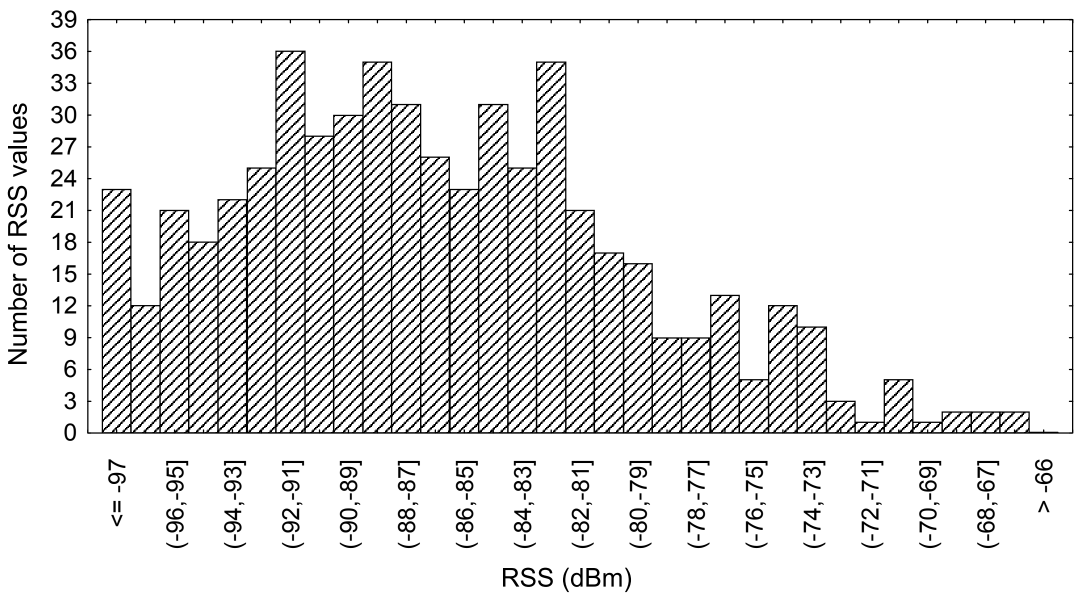


Figure 8.12. Histogram of downlink received signal strength (RSS; TAG 1, GMM cell).

The downlink average BER histogram is shown in Figure 8.13. For the downlink, approximately 65% of all data points had an average BER less than 1%. (Recall that average uplink BER was collected at the TMCO cell only.)

8.3.4 Low-Tier Microcell Site 3 Area Coverage Data

The test procedure followed and data collection methodology used for the low-tier testing are explained in Section 8.3.

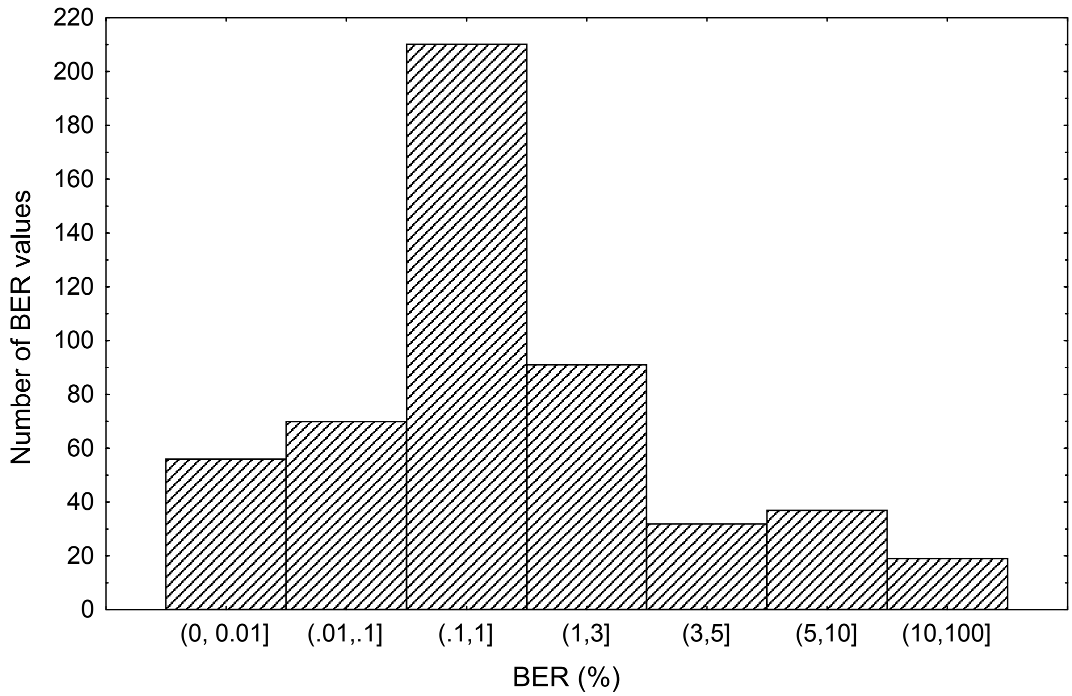


Figure 8.13. Histogram of average downlink bit error rate (BER; TAG 1, GMM cell).

Downlink RSS as a function of distance is shown in Figure 8.14. The data included in this figure are the overall data for this microcell with -100 dBm being the lowest recorded RSS. As in the high-tier cells, there is a large variation in RSS values for a given distance. This variation is caused by shadowing which is more pronounced because the base station is mounted on a traffic light pole in the middle of the street. Relatively strong signals (approximately -61 dBm) were seen relatively far away from the microcell site (approximately 1 mi). Those signals were recorded along 15th Street, where minimal shadowing occurred.

A rough estimate of the coverage area was determined by assuming that an RSS of -95 dBm or greater is desired. The measured RSS data along all of the routes driven within the cell were used to determine the coverage area. For this case, the coverage boundary was approximately 1.32 mi to the east. Coverage boundaries to the south and north were difficult to estimate. This was because all of the streets that run in a south-north direction and are the closest to the low-tier microcell site end abruptly after a few blocks, due to natural obstructions (a steep hill to the north and Boulder Creek to the south). Figure 8.15 shows the histogram of downlink RSS values for the Site 3 microcell. The mean RSS was -80.5 dBm and the standard deviation was 15.81 dB.

The downlink average BER histogram is shown in Figure 8.16. For the downlink, approximately 90% of all data points had an average BER less than 1%. (Recall that average uplink BER was collected at the TMCO cell only.)

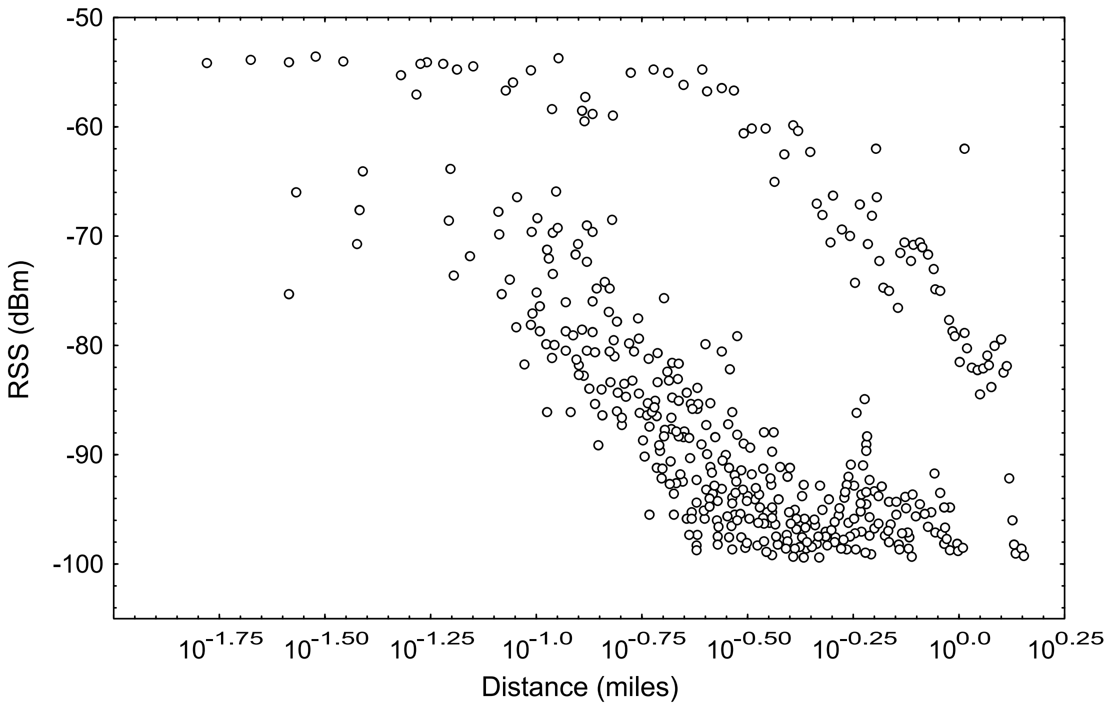


Figure 8.14. Downlink received signal strength (RSS) vs. distance (TAG 1, microcell site 3).

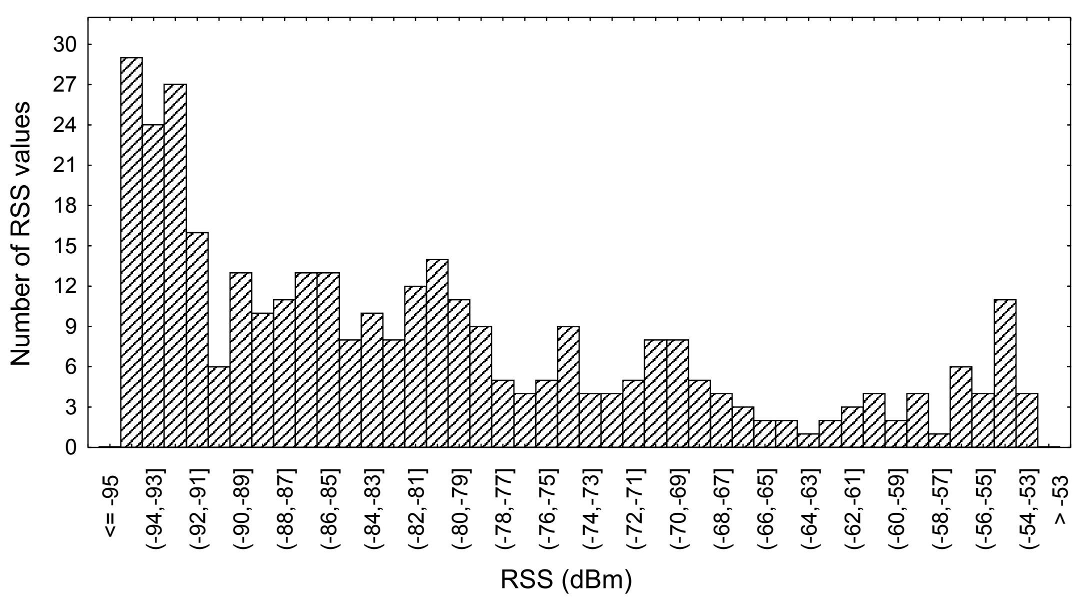


Figure 8.15. Histogram of downlink received signal strength (RSS; TAG 1, microcell site 3).

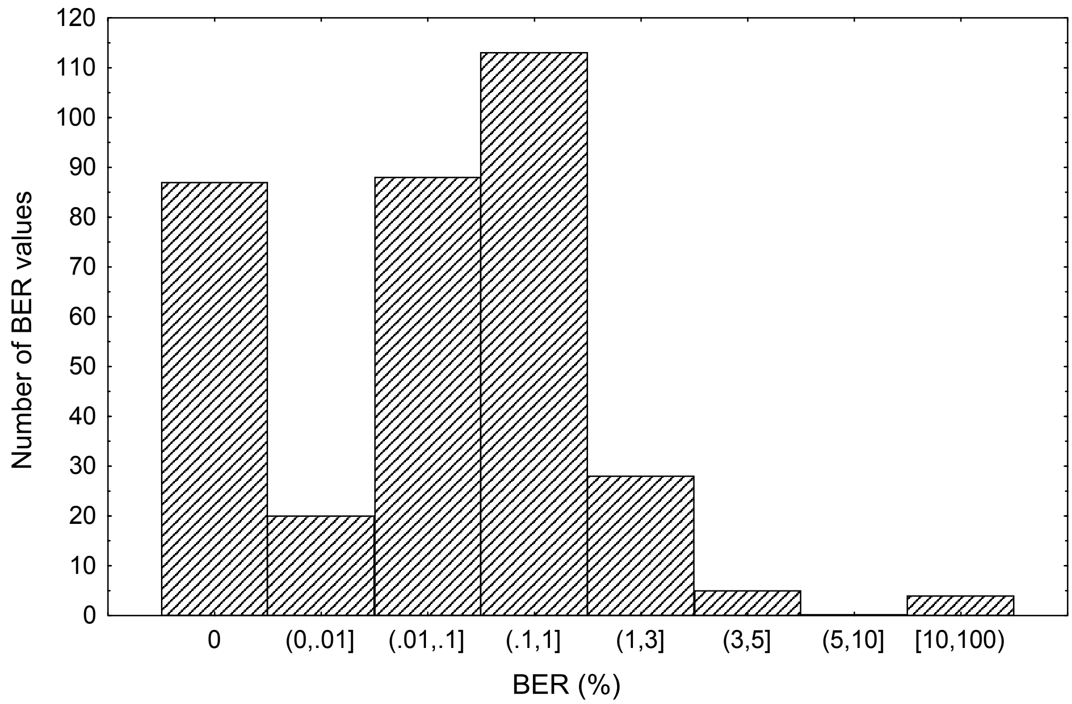


Figure 8.16. Histogram of average downlink bit error rate (BER; TAG 1, microcell site 3).

8.4 Handoff Testing

The TAG 1 technology was designed to support both low- and high-speed handoff. Therefore, handoff testing was conducted at speeds up to 60 mph. For the handoff testing, all high-tier cells were used. All sectors of the high-tier cells that were used during area coverage testing were activated for handoff testing. The low-tier microcell was not used during the handoff testing.

Handoff testing was performed by driving the measurement van on two routes that were chosen for handoff testing. One route was along Broadway between Norwood Avenue and Ludlow Street while the other was along Foothills Parkway between Jay Road and the hilltop overlooking Boulder just south of Boulder. These routes were driven in both the northbound and southbound directions.

In the TAG 1 handoff testing, handoff locations could only be pinpointed to within a 300-ft accuracy. Additionally, the exact difference between RSS values before and after a handoff and between BER values before and after a handoff could not be determined. Therefore, no data plots showing a change in values before and after handoff are available. A histogram of the average RSS values taken during all of the handoff measurement runs is given in Figure 8.17. The mean RSS was -82 dBm with a standard deviation of 10 dB. This mean RSS value is greater than the mean RSS value for any of the high-tier cells tested individually. This was expected, because the handoff routes were chosen in areas that had sufficient radio coverage to avoid dropped calls during the measurement runs.

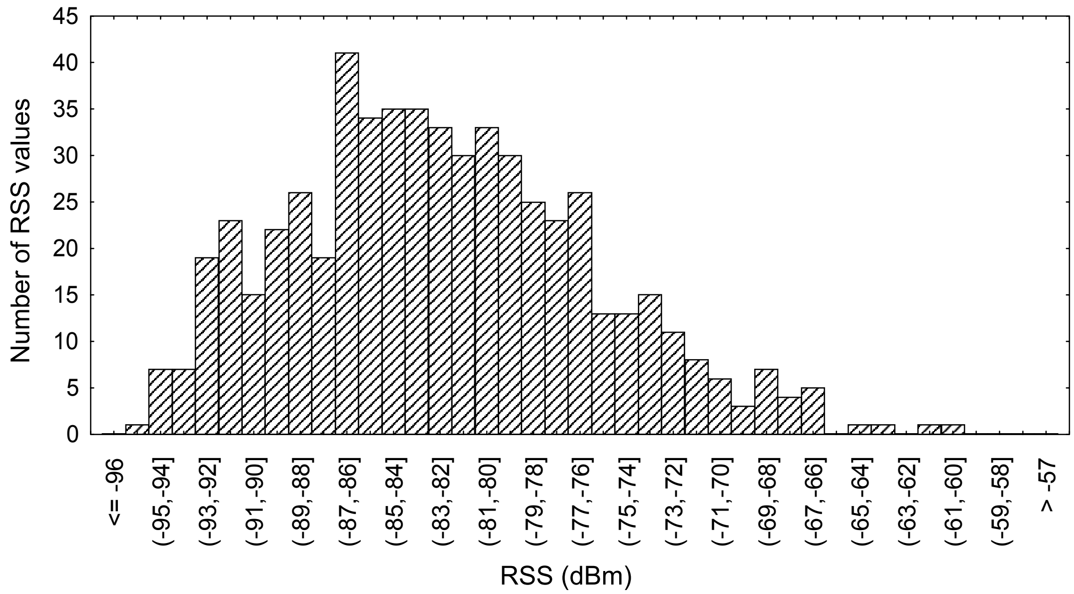


Figure 8.17. Histogram of average received signal strength (RSS) values taken during all handoff measurement runs (TAG 1).

8.5 Interference Testing

All interference measurements were conducted in downtown Boulder. The interference measurements consisted of both co-channel and adjacent channel interference measurements and were performed for the downlink only. This provided interference performance characterization for the mobile unit only. An antenna was mounted on the roof of the measurement van for these measurements. No interference measurements were taken for the base station receiver.

For the adjacent channel interference measurement, the WCO southwest sector was used as the intended source. The carrier for the intended source was set to 1875.625 MHz. The GMM north sector was used as the source for the adjacent channel interference. The carrier for the adjacent channel interferer was set to 1873.75 MHz, the channel immediately adjacent to the channel used for the intended source. For the adjacent channel interference testing, measurements were made under three different operating conditions: the interfering signal only, the desired signal only, and the desired signal in the presence of the interfering signal. Measurements under each operating condition were made on a separate measurement run along the same measurement route. The measurement route used for the adjacent channel interference measurements was along Broadway starting at the intersection of Broadway and Euclid Avenue and continuing north to Elder Street. For the interfering signal only measurements, a call was established at the beginning of the measurement route and downlink RSS data were collected, averaged, and saved to disk every 60 ft that the measurement van traveled. For the desired signal only measurements, a call was established and downlink RSS and BER data were collected, averaged, and saved to disk every 60 ft that the measurement van traveled. The same procedure was followed for the measurements of the desired signal in the presence of the interfering signal.

Figure 8.18 shows a plot of the average downlink BER as a function of the adjacent channel C/I. From this plot note that C/I values of -2 dB and greater provide a BER of less than about 1.25%. For C/I values less than -2 dB, while the average downlink BER generally increases, it does not increase monotonically as would be expected. A possible explanation for this is that an insufficient number of data points were taken to fully characterize the relationship between BER and adjacent channel C/I. Because the BER does not increase monotonically for C/I values less than -2 dB, a C/I threshold for which the BER begins to increase rapidly cannot be identified.

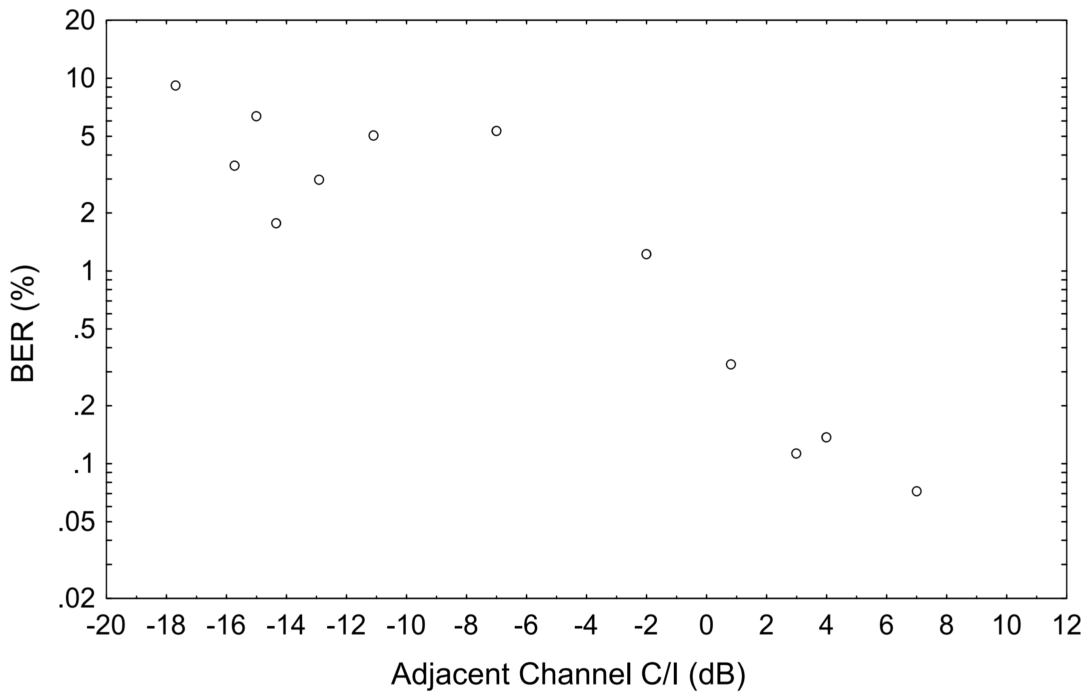


Figure 8.18. Average downlink bit error rate (BER) vs. adjacent channel carrier-to-interference ratio (C/I; TAG 1).

For the co-channel interference measurement, the WCO north sector was used as the intended source. The GMM north sector was used as the source for the co-channel interference. Both the GMM north sector and the WCO north sector were tuned to the same frequency (1873.75 MHz). As for the adjacent channel interference testing, for the co-channel interference testing, measurements were made under three different operating conditions: the interfering signal only, the desired signal only, and the desired signal in the presence of the interfering signal.

For the measurements of the desired signal only and the desired signal in the presence of the interferer, the measurement van followed a loop route. The van started at the intersection of Pearl Street and 15th Street, went east on Pearl Street, north on 19th Street, west on Mapleton Avenue, south on Broadway, east on Canyon Boulevard, north on 15th Street, and ended at the intersection of Walnut Street and 15th Street (one block south of the starting point). For the measurements of the interfering signal only, the measurement van followed the same loop route but started and ended at the intersection of Broadway and Mapleton Avenue,[16] thus completing the loop. Because the starting points along the loop route were different between the measurements for the interfering signal only and the other two operating conditions, the data could not be processed to provide a relationship between BER and the co-channel C/I.

8.6 Voice Quality

As discussed in Section 3.6, two types of voice quality measurements were made for the PCS JTC technology field trials in general: quasi-stationary measurements and handoff measurements. Both types of measurements were performed for the composite CDMA/TDMA (TAG 1) technology.

8.6.1 Quasi-stationary Measurements

Voice recordings and various objective measures including downlink RSS and uplink and downlink BER were collected at locations on a 0.5-mi grid that encompassed the expected coverage area for the TMCO, WCO, and GMM high-tier cell sites. Measurements were taken at 61 of the 82 locations that were identified for the quasi-stationary measurements as discussed in Section 3.6.1. These locations are shown on the map in Figure 8.19. For the TAG 1 voice quality testing, only one sector of one cell site was activated at a time. Intracell and intercell handoffs were not allowed.

At each location, data were collected as the measurement van traveled at one of two speeds. The vehicle traveled either 10 m or 100 m over the sample time. The particular vehicular speed used at each location (distance traveled over a fixed sample time) is shown on the map in Figure 8.19. Voice recordings were taken over the same sample time at all locations.

The measurements were taken at each location by establishing a call between the mobile and landline telephones. While the measurement van was in motion, an audio source tape was transmitted over the radio link in the uplink direction. After the uplink measurement was made, a downlink measurement was made. The source tape transmitted over each link was the same as that used for TAG 5 testing (see Section 3.6.1).

[16] The intersection of Broadway and Mapleton Avenue was the originally intended starting point and ending point of the loop route for all of the co-channel interference measurements under all three operating conditions. First, measurements were made for the interfering signal only along the loop route starting at this location. Next, for the measurements of the desired signal in the presence of the interferer, the call could not be established at the intersection of Broadway and Mapleton Avenue because the interference level was too high. The starting point of the loop route had to be changed to the intersection of Pearl Street and 15th Street (where the interference level was low enough to establish the call). Measurements of the desired signal in the presence of the interferer and of the desired signal only were then made along the loop route starting at the intersection of Pearl Street and 15th Street. Measurements of the interfering signal only were not repeated along the loop route starting at the intersection of Pearl Street and 15th Street.

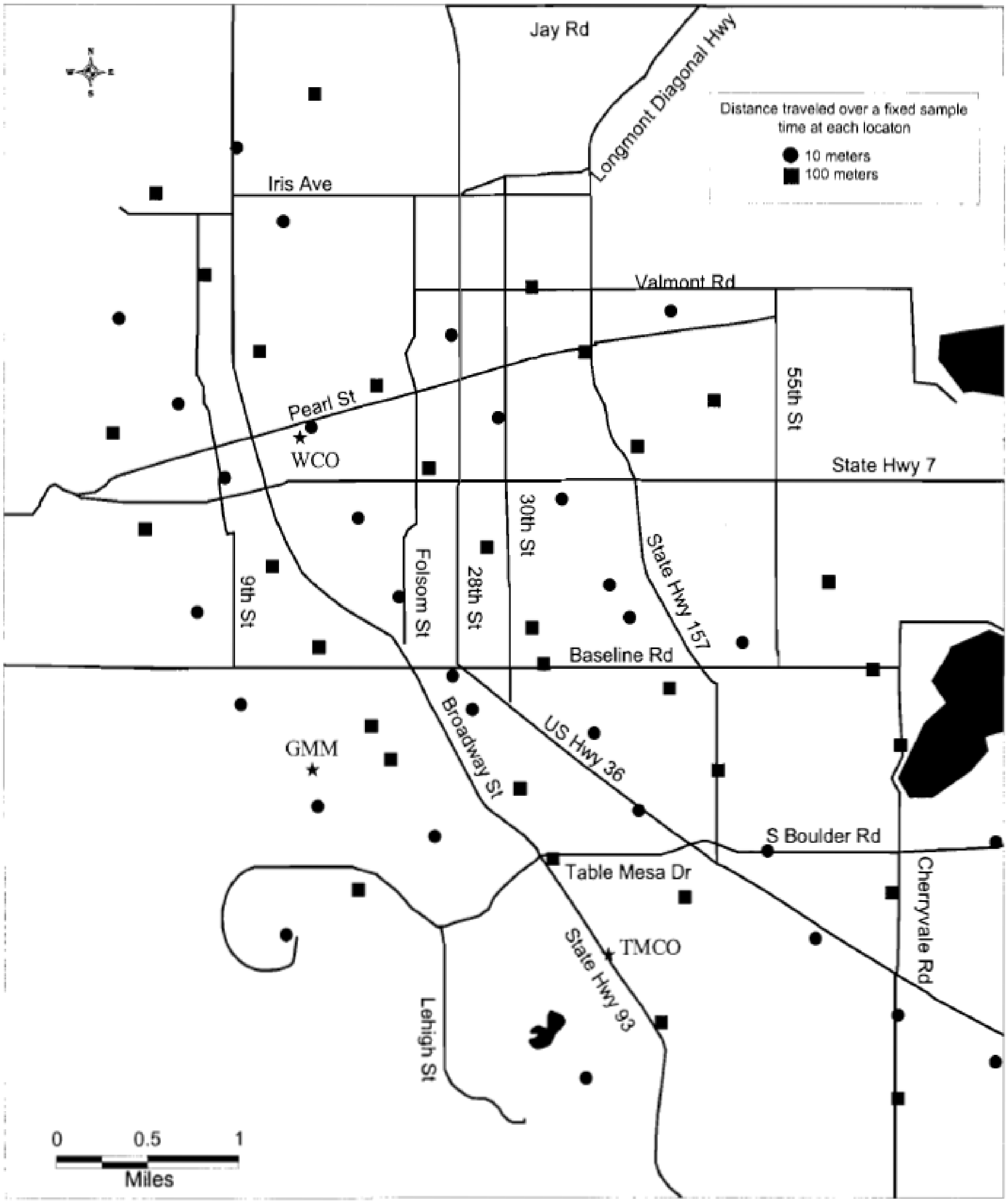


Figure 8.19. Quasi-stationary measurement locations and vehicular speed used at each location for TAG 1.

The received voice transmissions were recorded on digital audio tape at the receiver for the uplink and then at the receiver for the downlink. The recorded voice segments were then digitized with 16-bit resolution at a 22-Ksample/s rate and stored on a hard disk drive. At each location, the objective measures including average downlink RSS and average uplink and downlink BER were collected during separate measurement runs on the following day.

For the quasi-stationary measurements, voice quality of the voice segments was determined by both mean opinion score (MOS) and expert listener techniques. The following sections discuss these techniques and present the results based on the application of these techniques.

8.6.2 Mean Opinion Score Assessment

To accomplish the MOS testing, a pool of 32 subjects was recruited from the Boulder, Colorado area. Each of the following age groups were represented within the subject pool: 18-25, 25-35, 35-45, 45-55, and those over 55 years of age. There were an equal number of male and female subjects. The subjects were cordless, noncellular telephone users.

Four groups consisting of eight subjects from the subject pool were formed. The subjects were asked to rate voice segments by answering the three questions listed in Section 3.6.2 after each segment was presented.

First the subjects in each of the 4 groups were presented 10 practice voice segments to rate. The practice segments included one 64-kbps wireline voice segment, two voice segments collected from field measurements (one with an expert listener rating of definitely acceptable and one with an expert listener rating of unacceptable), and seven segments created in a laboratory environment by the TAG 1 vendor. The laboratory segments simulated speech with various BER's in three different environments: residential, urban, and rural. The seven segments represented the following environments and BER's: unimpaired speech, residential with a BER of 1%, residential with a BER of 10%, urban with a BER of 1%, urban with a BER of 10%, rural with a BER of 1%, and rural with a BER of 10%.

After the practice segments were presented, the subjects in each of the 4 groups were asked to rate 33 voice segments: 3 reference voice segments and 30 voice segments from the field trial measurements. Every listener within a group listened to the same voice segments. The reference voice segments included one 64-kbps wireline voice segment and two voice segments collected from field measurements (one with an expert listener rating of definitely acceptable and one with an expert listener rating of unacceptable). The 30 voice segments from the field trial measurements came from the uplink or downlink measurements at a portion of the 61 measurement locations.

The number and type (male or female) of sentences that were used and the order in which they were used to form a voice segment were the same as that described in Section 4.6.2. Subjects were given two breaks during the testing session. After all segments were presented, subjects filled out a post-trial questionnaire.

For each voice segment, voice quality ratings (answers to the question "How would you rate the overall quality of the sound?") from each subject within a group were averaged to obtain an MOS. Voice segments from only 57 out of the 61 locations were used in the analysis since the voice segments from 4 of the 61 locations were not successfully tested. The results from all four of the groups are shown in the histogram in Figure 8.20. Overall, the voice segments were rated favorably, with 84.2% of the segments rated between fair and excellent. The average MOS was 3.65 and the standard deviation was 0.63.

Figures 8.21 and 8.22, show histograms of MOS's for the uplink and downlink, respectively. The average MOS for the uplink was 3.54 and for the downlink was 3.76. A t-test revealed that there is no statistically significant difference in the average MOS's between the uplink and downlink.

The relationship between the MOS's and some of the objective measures was initially investigated by generating some scatter plots. Figure 8.23 shows the relationship between the MOS's and average downlink RSS. In Figure 8.23, variation in MOS's tends to lessen as RSS values increase. MOS's tend to degrade as the RSS value drops below about -89 dBm. Figures 8.24 and 8.25 show the relationship between the MOS's and the average BER for both the uplink and downlink, respectively. From Figure 8.25, note that the MOS tends to degrade as the average downlink BER increases, as expected. As seen in Figure 8.24, this trend is not as evident for the uplink.

Pearson product-moment correlations were performed to determine the correlation between MOS and average downlink RSS and MOS and average downlink BER. The correlation coefficient between MOS and average downlink RSS was 0.40 and that between MOS and average downlink BER was -0.75. This suggests that a fairly strong linear relationship exists between MOS and average downlink BER; a weaker linear relationship exists between MOS and average downlink RSS. The correlation coefficient between the average downlink RSS and the average downlink BER was -0.51.

Spearman rank correlations were performed to determine the correlation between the ranks of MOS and the ranks of average downlink RSS and between the ranks of MOS and the ranks of average downlink BER. The Spearman rank correlation coefficient between MOS and average downlink RSS was 0.35 and that between MOS and average downlink BER was -0.49. These correlation coefficients between MOS and the averaged objective measures are lower than the Pearson product moment correlations; this suggests that a consistently increasing or decreasing relationship between MOS and the objective measures does not exist. The Spearman rank correlation coefficient between the average downlink RSS and BER was -0.66 and is greater than the Pearson product moment correlation coefficient between these measures.

Next, a Pearson product-moment correlation was performed to determine the correlation between MOS and average uplink BER. The correlation coefficient between MOS and average uplink BER was -0.20. Therefore, a strong linear relationship between MOS and average uplink BER does not exist.

A Spearman rank correlation was performed to determine the correlation between the ranks of MOS and the ranks of average uplink BER. The Spearman rank correlation coefficient between MOS and average uplink BER was -0.36. This correlation coefficient, while higher than the Pearson product moment correlation coefficient, is still fairly low and suggests that a consistently increasing or decreasing relationship between MOS and average uplink BER does not exist.

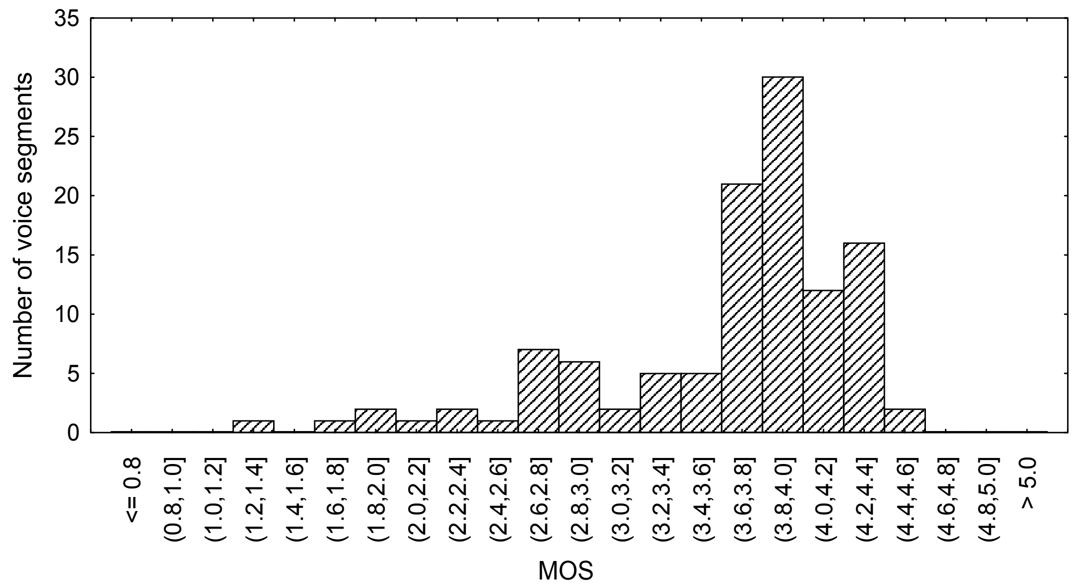


Figure 8.20. Histogram of mean opinion scores (MOS's) for all voice segments (TAG 1).

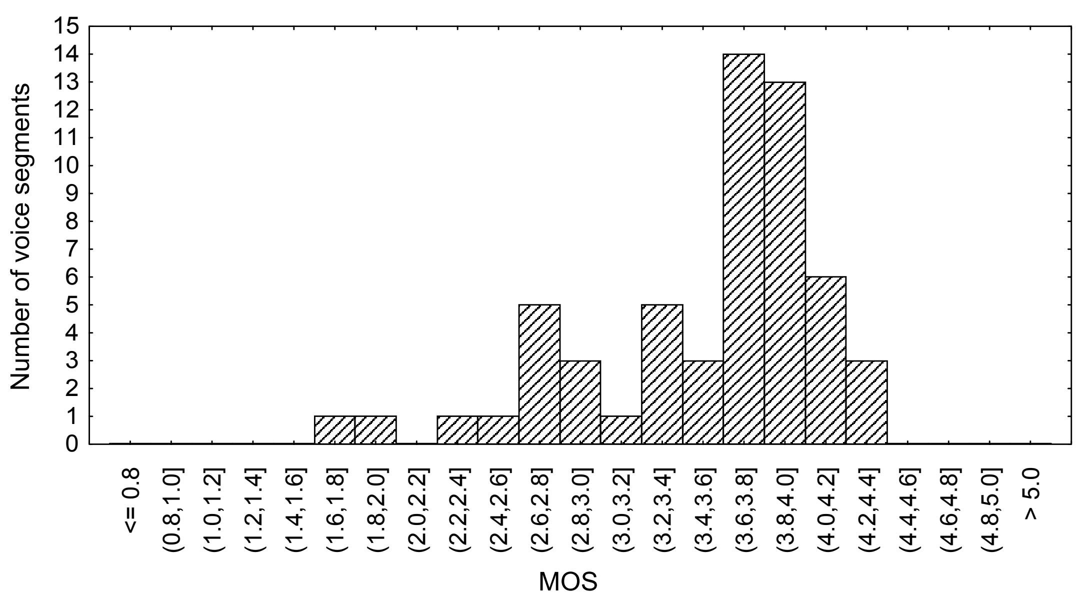


Figure 8.21. Histogram of mean opinion scores (MOS's) for the uplink (TAG 1).

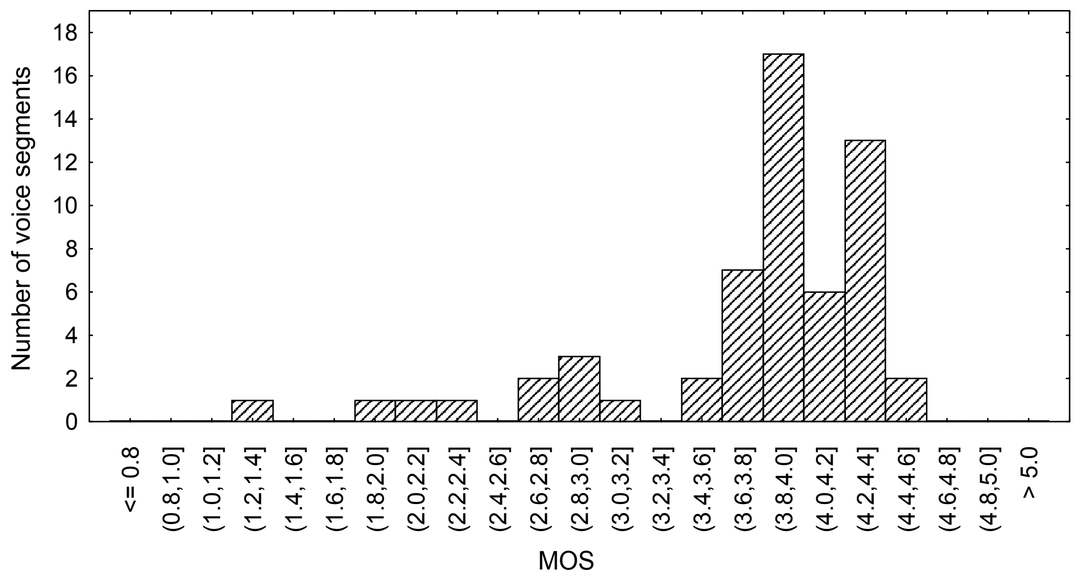


Figure 8.22. Histogram of mean opinion scores (MOS's) for the downlink (TAG 1).

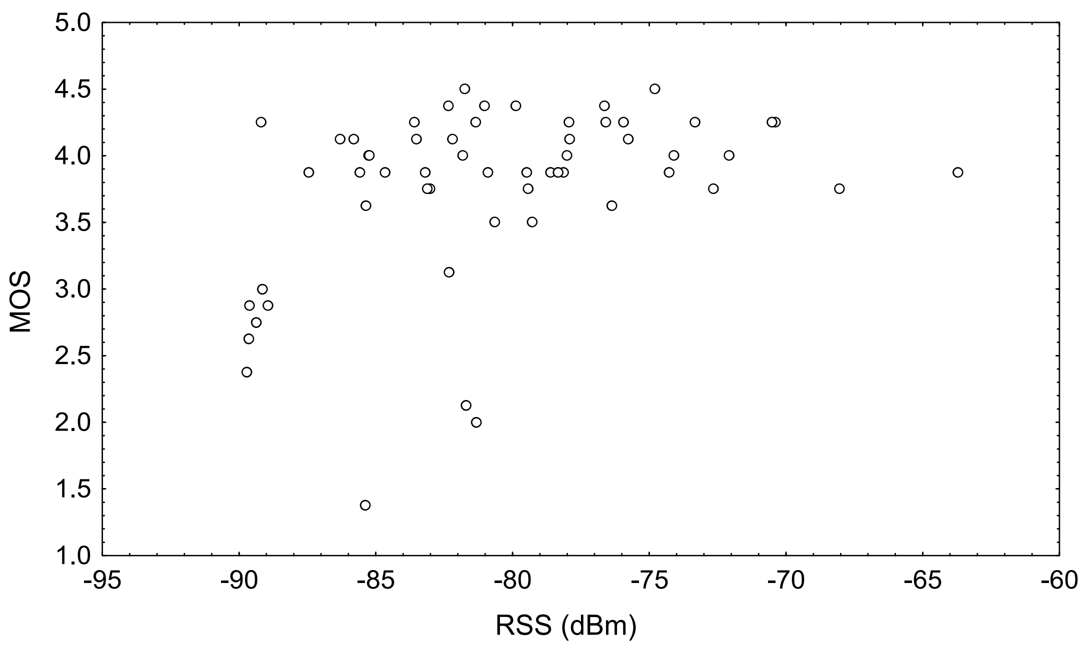


Figure 8.23. Mean opinion score (MOS) vs. average received signal strength (RSS; TAG 1).

Note that as in the voice quality data analysis of the previous JTC PCS technology field trials, the objective measures were averaged over the entire length of the voice segment. By analyzing the instantaneous variation or possibly minimum and maximum values of the objective measures within the voice segment, further insight may be gained on the behavior of MOS's and higher correlations to MOS's might be obtained.

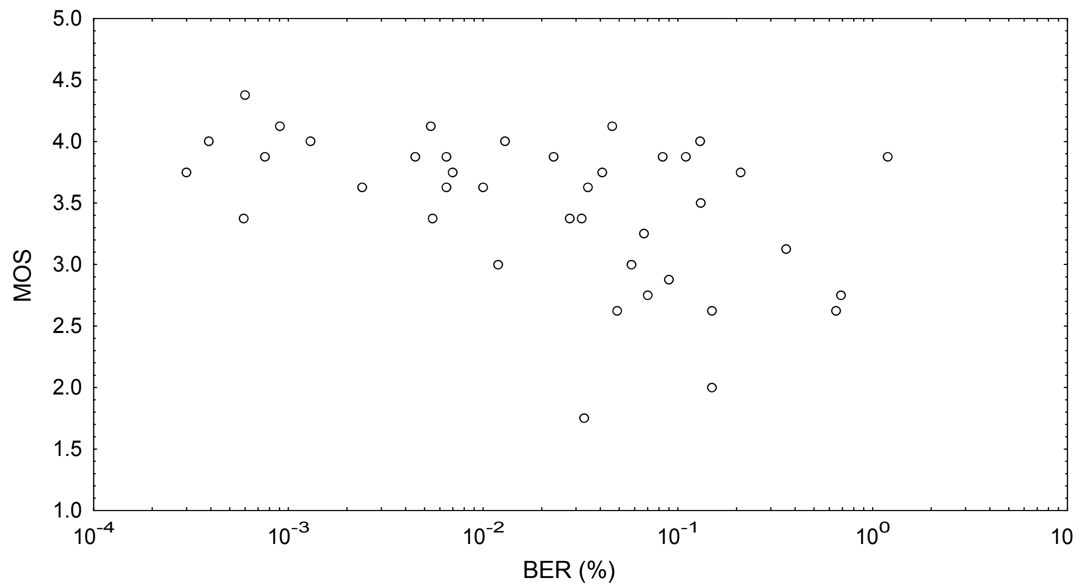


Figure 8.24. Mean opinion score (MOS) vs. uplink bit error rate (BER; TAG 1).

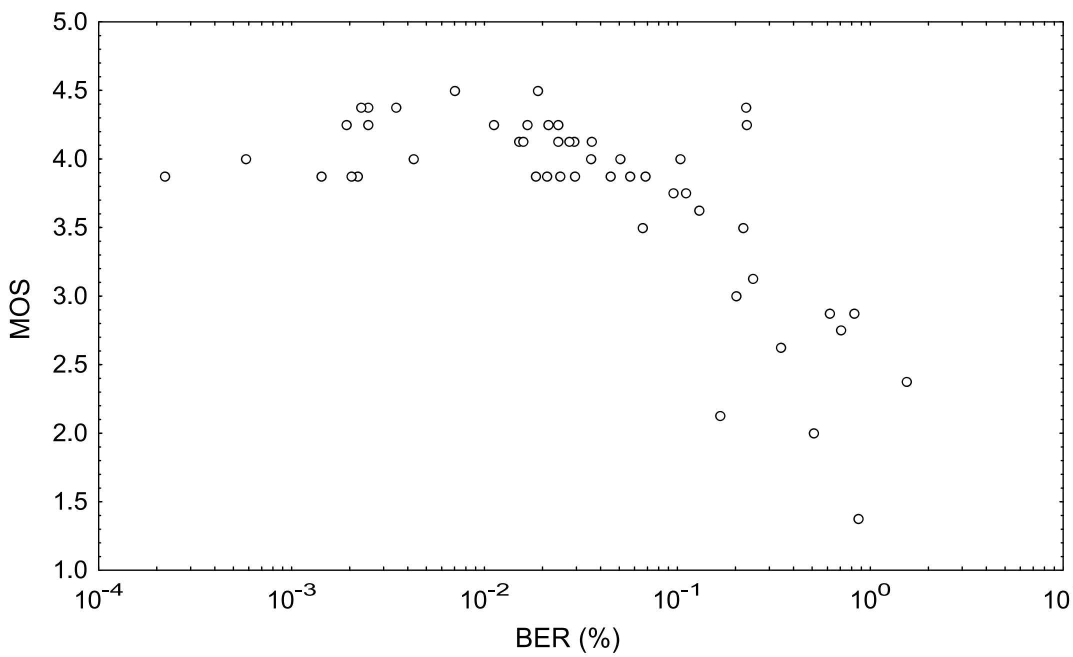


Figure 8.25. Mean opinion score (MOS) vs. downlink bit error rate (BER; TAG 1).

By gathering listeners' comments from post-test questionnaires, more information about the nature of MOS's was obtained. Namely, it is evident from questionnaires that there are several types of distortions in quality possible in the voice segments according to listeners:

1) "static,"
2) "background noise,"

3) “echo,” and
4) “muffled or hollow sound.”

Note that these are the exact words used by listeners. The nature of these distortions are likely judged differently by different listeners. Intelligibility and speaker recognition are two main aspects of perceived quality. For most of the voice segments, intelligibility remained high. As a result, overall MOS’s were high and overall listener’s comments were quite positive.

8.6.3 Expert Listener Assessment

In addition to being rated by listener panels in MOS testing, the voice segments were rated by an expert listener. The expert listener ratings followed the identical procedure as in the PCS 1900 (TAG 5) testing. This procedure is described in Section 3.6.3.

Figure 8.26 shows the relationship between expert listener ratings and percent acceptability (the percentage of listeners rating a given voice segment as acceptable). The boxes represent the middle half of the data (from the 25th percentile to the 75th percentile). The solid circles represent the median percent acceptabilities for each of the expert listener ratings. The lines extending out of the boxes depict the spread of the data.

The expert listener ratings were very good indicators of percent acceptability for the voice segments in the TAG 1 testing. The expert listener ratings accurately predicted the percent acceptability for 105 out of the 114 voice segments evaluated by listener panels.

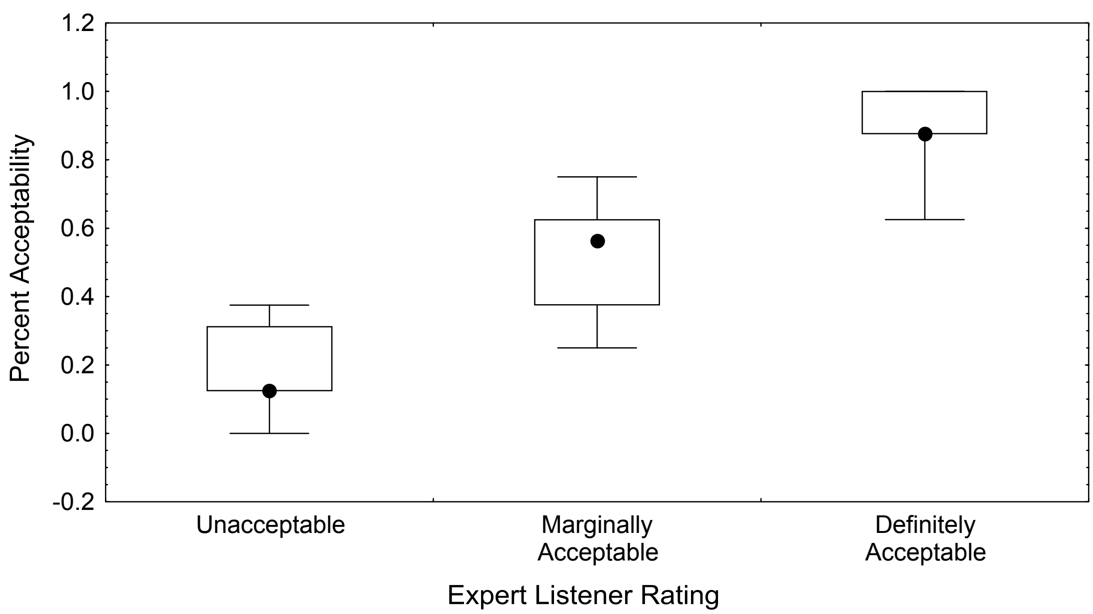


Figure 8.26. Percent acceptability vs. expert listener rating (TAG 1).

The Pearson product-moment correlation coefficients between MOS and uplink and downlink percent acceptability were 0.90 and 0.87, respectively, showing a strong linear relationship between these measures, as would be expected. The Pearson product-moment correlation coefficients between MOS and uplink and downlink expert listener ratings were 0.87 and 0.92, respectively, indicating a strong linear relationship between these measures. Expert listener ratings were also highly correlated with percent acceptability with Pearson product-moment correlation coefficients of 0.89 and 0.88 for the uplink and downlink, respectively.

8.6.4 Voice Quality Handoff Measurements

Continuous voice recordings were made as the mobile unit traveled along routes through handoff areas. While the measurement van was in motion, an audio source tape was transmitted over either the uplink or downlink. (Uplink and downlink voice recordings were made during separate runs.) The source tape consisted of Harvard sentences and was played continuously as the measurement van traveled along each route. The received voice transmissions were recorded on digital audio tape at the receiver for either the uplink or downlink. Continuous voice recordings were made along the route until the call was finally dropped. The routes were selected according to previous tests at the BITB. One route was driven along Broadway, at a vehicular speed of 30 mph. The second route was driven along Foothills Parkway, at a vehicular speed of 60 mph. Six measurement runs were conducted along each route. Three measurement runs were made with the measurement van traveling southward along the route: one for collecting a voice recording on the uplink, one for collecting a voice recording on the downlink, and one for recording downlink RSS and BER. The three other runs collected the same data but for the measurement van traveling northward along the route. Voice quality was assessed using the expert listener methodology described in Section 3.6.3.

For the voice quality handoff testing, an expert listener rating was made for each 4-s period of the continuous voice recordings taken along a measurement route. In general, voice quality was good throughout most of the handoff testing. The handoffs were distinguishable to the expert listener and were characterized by brief periods of unacceptable voice quality.

8.7. Manufacturer's Statement

The statement provided by Omnipoint Corporation is included in this section. This statement is identical to that given in [7], except for some minor editorial changes.

Omnipoint Corporation would like to acknowledge the efforts of all TAG 1 members and supporters in the successful completion of the Composite CDMA/TDMA technology field trial in Boulder. Equipment was supplied to demonstrate the Composite CDMA/TDMA PCS air interface in the BITB as part of the standardization requirements of the JTC.

The TAG 1 technology was the only PCS technology to demonstrate both high-tier (macrocell) and low-tier (microcell) performance and capability. The low-tier field testing was conducted with the same equipment as that used for the high-tier field testing. The TAG 1 technology was the only PCS technology to field its equipment outdoors (in weatherproof enclosures) for high-tier testing, taking advantage of its small size.

The TAG 1 composite CDMA/TDMA system performed quite well as Section 8 of this report shows. The system demonstrated excellent voice quality and good coverage with very low base station transmit power: 10-25% of the transmit power used by the other high-tier PCS technologies during the JTC PCS technology field trials. The TAG 1 field trial also demonstrated deployment flexibility for fielding the same equipment in different environments (i.e., microcell and macrocell).

The TAG 1 equipment fielded in the BITB was an early prototype system (Version 2.03a) and the BITB did not allow for optimizing system performance through cell site placement or antenna configurations. As can be noted from Section 8.6 of this report, voice quality was very good. Subsequent equipment development and commercially available equipment have improved receiver sensitivity, receiver selectivity, and greatly enhanced handoff algorithms. These system enhancements would improve coverage, interference rejection, and handoff performance as seen at the BITB, consequently overall system performance would be even better.

Note that the point-to-point microwave T1 link between the GMM and WCO sites at the BITB used a 2.4-GHz system operating in an unlicensed band. For future reference, Omnipoint would strongly urge all standards bodies to implement tests using backhaul from the base stations to the switch that is protected from any interference. This unlicensed band is particularly prone to interference on an episodic basis. Thus, it is possible that the results of all TAG groups using this link could have been susceptible to unmeasureable interference. Use of licensed frequencies in the future would eliminate (or greatly reduce) this susceptibility.

TAG 1 would like to thank U S West Advanced Technologies for making the BITB facilities available for these tests. Omnipoint sincerely appreciates the efforts of the U S West Advanced Technologies team (J. Corliss, V. Jevremovic, M. Owens, and J. Matthews) for the long hours and dedication in making the field trial a success. Omnipoint would also like to thank the ITS team (R. Sanchez, J. Mastrangelo, and J. Wepman) for its participation as the independent observer collecting data and monitoring the tests.

9. SUMMARY

Draft standards for six air-interface technologies for licensed PCS were developed by the Joint Technical Committee on Wireles Access (JTC). These draft standards were then forwarded to the American National Standards Institute (ANSI) to be processed for acceptance as formal standards. The six air-interface technologies include the IS-95 based CDMA, IS-136-based TDMA, personal access communication system (PACS), PCS 1900, Omnipoint TDMA/CDMA, and Wideband CDMA technologies.

Technology field trials for the six air-interface technologies were performed at the U S West Boulder Industry Test Bed (BITB) in cooperation with the JTC. The purpose of the field trials was to 1) demonstrate the performance of the air interface for each technology and 2) to fulfill the JTC requirement that each technology undergo a technology field trial before being forwarded to the ANSI.

Both high-tier and low-tier systems were tested in the JTC PCS technology field trials. The same configuration (cell site layout, antenna type, and antenna orientation) was used for all of the systems tested as high-tier systems. Similarly, another configuration was used for all systems tested as low-tier systems. These configurations were fixed throughout the duration of the field trials and did not vary from one technology to another. This provided a common environment for testing. It did not, however, provide an opportunity for optimizing the performance of each technology. Field testing for all six of the air-interface technologies typically consisted of four general types: area coverage testing, handoff testing, interference testing, and voice quality testing.

While, in general, the same fundamental types of measurements were made for each technology, some variations in the types of measurements are evident, due to differences between each technology. Also, because each technology was different and the mechanisms for reporting data were different, the reported data is sometimes given in different formats. Differences also existed in what types of data were available at the uplink and downlink for the different technologies.

This report describes the cell site configurations, the system configurations, the types of measurements performed, and the results of the analyses of the measured data taken during the six JTC technology field trials performed at the U S West Boulder Industry Test Bed. The report is intended to be an easily accessible reference that represents a consolidation of the six individual JTC reports written for each of the six technology field trials. The original JTC reports present both statistical analyses of the data and maps showing the data as a function of geographical location. In this report, to provide a more concise document, only the statistical analyses of the data are presented. More detailed information about each one of the field trials is available in the individual test reports submitted to the JTC for each air-interface technology [1, 2, and 4-7]. In both the original JTC reports and in this report, no comparison of the different technologies and no comparison of the performance of the different technologies during the field trials is made.

10. REFERENCES

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